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ABSTRACT

Presented are the proceedings of the first international Congress on "Space for Mankind's Benefit" organized by the Huntsville Association of Technical Societies and held November 15-19, 1971, at Huntsville, Alabama. Following introductory statements, a total of 45 articles read in 10 sessions are incorporated. The session headings are: Man in Near-Earth Space--Concepts, Logistics, Operations; Fundamental Benefits of the Space Program; Benefits of Orbital Surveys and Space Technology to Environmental Protection; Earth Resources Observations Through Orbital Surveys; Benefits to Telecommunications, Navigation, and Information Systems; Meaning of Space to the Natural Sciences; Space Manufacturing Benefits; Benefits to Future Power Generation and Energy Production; General Technology Utilization in the Public Sector; and Social Benefits and International Cooperation Through Space. Information on application of space technology to medicine, medical research, and health care is dealt with by the session "Benefits to Medicine, Medical Technology and Biotechnology." Also included are a list of participating societies and associations, a report on the forum discussion, and the names of session chairmen. (CC)

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# SPACE FOR
# MANKIND'S BENEFIT

A space congress held at
HUNTSVILLE, ALABAMA
November 15–19, 1971

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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# SPACE FOR MANKIND'S BENEFIT

The proceedings of a space congress
held November 15–19, 1971, at Huntsville, Alabama
sponsored by the National Aeronautics and Space Administration and
the Huntsville Association of Technical Societies

*Prepared at*

George C. Marshall Space Flight Center

*Edited by*

Jesco von Puttkamer and Thomas J. McCullough

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# INTRODUCTION TO THE SPACE CONGRESS THEME

By Jesco von Puttkamer
General Chairman

The papers published in this volume are the proceedings of the first international Congress on "Space for Mankind's Benefit," organized by the Huntsville Association of Technical Societies (HATS) and held November 15-19, 1971, at Huntsville, Alabama. They are intended to provide accurate and concise representation of space program benefits.

The individuals and organizations working through HATS have been supporting the Space Benefits Congress because it is their belief that, in order to fully evaluate and judge the space program against its much publicized costs, Americans should be given more and better opportunities to avail themselves of the facts of space technology benefits and to understand that there is considerably more utility to the space program than the excitement and thrill of a manned flight. In a world of an ever increasing number of social and economic priorities competing for limited funds, it appears that rather than confronting the concerned citizen with rhetoric statements and unsubstantiated claims about the need for a space program — an approach which would do more damage than good — it behooves us to actually go in and dig out the facts, and then let them stand for themselves. The purpose of the HATS Space Congress thus became one of assembling and disseminating a compendium of factual benefits of space technology on earth.

The need for this dialogue with the public is very real and ever increasing. Public interest in the American space program has been dwindling rapidly in the past months since the successful lunar landing by Armstrong and Aldrin. In direct relation to the decline in public support the space program has entered a downhill trend in scope, activities, and aspirations which is becoming increasingly alarming to those who are convinced that it has a justifiable place in today's complex society, has something to offer, and is indeed one of our more important obligations to the future. On the other hand, we all know the difficulties of economically justifying a government-financed technology development program.

Does the world owe the space program a living? The evidence accumulated so far (and reflected in the following pages) and the projections of realistic applications of space in the future very definitely say it does. Future generations would justly condemn us if we fail to follow through on the fantastic successes that we have achieved in space. The breathtaking photographs from space showing earth of the size of a mere ping-pong ball have illustrated one great fact, namely, that our earth is really nothing but a large space vehicle. If we keep this analogy in mind, then the relationship of space technology and space tools to earth's ecology and "subsystems" becomes more apparent. To actually engineer our world to keep it from running down, to really service it, man has to be able to go beyond its boundaries, into space.

To help the public learn and understand more about this fact, that is the basic purpose of the Space Congress.

The papers in the following are authored by experts in their respective areas of space technology applications. They present a representative cross section of space benefits and are offered as a small part of the evidence supporting the contention of the space program as an obligation to the future.

# SPACE FOR MANKIND'S BENEFIT
# A SPACE CONGRESS FOR THE NONAEROSPACE PUBLIC

## Message from the Chairman

By Jesco von Puttkamer
General Chairman

On behalf of the Huntsville area technical organizations, the Huntsville Association of Technical Societies (HATS) is extending you a very warm welcome to the first International Congress on "Space for Mankind's Benefit" in hospitable Huntsville, Alabama.

With this Congress, HATS is attempting to depart from the traditional format of professional technical meetings at which highly sophisticated papers are read in technical language to a specialist audience. Instead, topical presentations and discussions will be in popular language, and the audience will be largely nontechnical men and women from outside the aerospace field, while not excluding the latter. However, although the Congress is directed toward the more general public, the speakers are experts in their respective areas of space technology applications, as are indeed the session chairmen. By combining expert speakers with general audience and encouraging question-and-answer dialogue between them, we hope to achieve our overall Congress goal, namely, to help the public learn and understand more about the benefits of the space program.

The theme of the Congress is intended to remind us of one of the basic purposes of the U.S. space program. The official National Aeronautics and Space Act of July 29, 1958 (Public Law 85-568), stated, "The Congress hereby declares that it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all mankind." While the goals of the space program include the advancement of human knowledge of the universe and the improvement of our ability to operate in the space environment, the utility of the space program for practical purposes on earth is a topic of increasing political and public concern. Thus, while space research is of course not primarily directed toward immediate direct benefit to the public, it is nonetheless important as a potential source of practical dividends.

A number of years ago, when the space program first stretched its fledgling wings, many people in America and throughout the world started to ask, "Why conquer space?" or "Why send men into space?" The reasons given at that time were political and spiritual. With no evidence to show for its practical utility, it was an impossible job indeed to convince people about its direct relevance to their more immediate needs and pressing problems. As a consequence, many people viewed the space program as an exclusive undertaking by a small, select segment of the population.

Today, the space program has piled up evidence to the contrary. People are still asking, "Why conquer space?", but for the first time it is now possible to answer this question with down-to-earth reasons, substantiated by hard-hitting facts: Because we are getting valuable scientific knowledge from space about the earth, the sun, the universe, and man himself, which we could not get in any other way. Because the space program is producing more useful new technology per dollar invested than any other organized activity in America today. Because it has proven to be an excellent hotbed for forcing new technology, which in turn raises our national productivity and prosperity and increases our ability to solve pressing social problems of today's urban society. Because the space program is one of the few national programs which actually creates resources rather than uses them. Because space exploration is needed as inspiration for modern man. And because it furthers international cooperation and favors global peace.

Since the space program depends on public support, the future of an effective space program, and with it the future of our social, technological and spiritual development, is dependent upon the realization by the general public that the space program has indeed a justifiable place in today's complex society. Support of space exploration can only be expected from a public and its congressional representatives that are aware of the practical returns accruing from the national space investment.

The HATS Space Congress is a first attempt at providing an opportunity for the public to learn about these facts. Its purpose is to draw together and present a cross-section of the many benefits the United States and mankind have received and will receive from the space program.

The Congress "Space for Mankind's Benefit" is dedicated to Mankind at large and its hope for the future — the space program.

## PARTICIPATING SOCIETIES AND ASSOCIATIONS

*Alabama Society of Professional Engineers (ASPE)

*American Society of Mechanical Engineers (ASME)

*American Institute of Industrial Engineers (AIIE)

American Society of Tool and Manufacturing Engineers (ASTME)

Society of Non-Destructive Testing (SNT)

American Society for Metals (ASM)

*Institute of Electrical and Electronic Engineers (IEEE)

*American Institute of Astronautics and Aeronautics (AIAA)

*Instrument Society of America (ISA)

American Ordnance Association (AOA)

American Nuclear Society (ANS)

American Optical Society (AOS)

Society of American Military Engineers (SAME)

Society of Aerospace Material and Process Engineers (SAMPE)

*Society of American Value Engineers (SAVE)

American Society for Quality Control (ASQC)

Society of Logistics Engineers (SOLE)

Air Force Association (AFA)

Reserve Officers Association (ROA)

*Rocket City Astronomical Association (RCAA)

*Huntsville General Electric Engineers Association (HGEEA)

*American Astronautical Society (AAS)

*Madison County Medical Society

Society for Technical Communication (STC)

Chicago Technical Societies Council

American Society of Agricultural Engineers

National Aerospace Education Council

Society of Women Engineers

Soil Conservation Society of America

The Health Sciences Communication Association

***HATS Member**

# SPACE BENEFITS SESSIONS AND THEIR CHAIRMEN

## Session I: Man in Near-Earth Space: Concepts, Logistics, Operations

The purpose of this session is to familiarize the participants with the major space program elements from which space applications on earth will derive; i.e., the session will "set the stage" for the Congress theme. Overview presentations will highlight Skylab and its experiments and applications, the space station and its practical contributions to life on earth, the Space Shuttle, Research and Applications Modules, Earth Resources Satellite programs, and others.

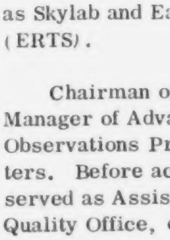
Chairman of the session is Dr. William R. Lucas, the Deputy Director, Technical, of the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC) in Huntsville, Alabama. A specialist in materials, Dr. Lucas was formerly the Director of Program Development at MSFC and prior to that the Director of MSFC's Propulsion and Vehicle Engineering Laboratory. Dr. Lucas joined the rocket development team in Huntsville in 1952. As a member of that team, he later directed the material aspects of the successful nose cone development of the Army's Jupiter missile. Dr. Lucas holds the NASA Medal for Exceptional Science Achievement (1964), the Hermann Oberth Award for outstanding individual contributions to the fields of aeronautics and astronautics (1965), the NASA Exceptional Service Medal for his contribution to the Apollo VIII circumlunar flight (1969), and again a NASA Exceptional Service Medal for his contributions to the Apollo XI lunar landing mission.

## Session II: Fundamental Benefits of the Space Program

Session speakers of responsibility will discuss some of the more fundamental but often overlooked benefits of the space program which will continue to have profound effects on this country and its people far exceeding those of the more "down-to-earth" practical spin-offs. The emphasis in this session is on benefits to human problem solving, to the economy and national prestige, to global peace and cooperation, and to our understanding of the universe and of ourselves.

The session is chaired by Joseph F. Clayton, the General Manager of the Bendix Corporation's Aerospace Systems Division. Prior to accepting that position, Mr. Clayton was Assistant General Manager and Program Director for the Apollo Lunar Surface Experiments Package (ALSEP) at Bendix until 1968, and prior to that the Director of Program Management. Holding an A.B. degree from Boston College (1943), an A.M. degree in Physics from Tufts University (1948), and an M.S. degree in Applied Science from Harvard University (1949), Mr. Clayton joined Bendix in March 1949. He has authored numerous papers on missile guidance and extraterrestrial scientific exploration, and originated five patents in radar and radiation detection techniques.

## Session III: Benefits of Orbital Surveys and Space Technology to Environmental Protection



The purpose of this session is to explain the possibilities of utilizing space-acquired data for observing the earth's environment and identifying causes of degradation as they occur. Emphasis will be placed on current state-of-the-art technology with special attention to data acquisition capabilities for such systems as Skylab and Earth Resources Technology Satellite (ERTS).

Chairman of the session is Theodore A. George, Manager of Advanced Studies Programs, Earth Observations Programs Office, of NASA Headquarters. Before accepting that position, Mr. George served as Assistant to the Commissioner, Water Quality Office, of the Environmental Protection Agency (EPA). Prior to that, he was Manager of Earth Resources Flight Programs at the NASA Headquarters since 1967. Previously he held government engineering and technical positions, including Principal Engineer of Manned Missions Experiments in the NASA Manned Missions Program Office since 1964, Deputy Director of Nuclear Test Detection in DOD since 1960, and Manager of the Discoverer Project at the Advanced Research Projects Agency (ARPA). Mr. George received B.S. degrees in Mathematics and Aeronautical/Mechanical Engineering from George Washington University and Catholic University, and an M.A.E. in Aeronautical/Astronautical Engineering from Catholic University.

## Session IV: Earth Resources Observation Through Orbital Surveys

The purpose of this session is to demonstrate space technology applications to the exploration and management of earth resources. Examples of remote observations and their interpretation for inventories and other practical utilizations will be given in areas such as agriculture and forestry, geography and mapping, geology and hydrology, and others.

The chairman of the session, William A. Radlinski, is Acting Director of the U.S. Geological Survey (USGS) in the U.S. Department of the Interior. Before that, Mr. Radlinski has held various positions in the Topographic Division of the USGS for the past 20 years, following his employment by the Army Map Service as a stereo operator. Mr. Radlinski is highly regarded in the fields of topography and photogrammetry. He has published several articles on the subject and has served as associate editor of the Manual of Photogrammetry, Third Edition. He has been honored with a Distinguished Service Award, the Department of the Interior's highest award, and with two Presidential Citations for Meritorious Service of the American Society of Photogrammetry. Mt. Radlinski in Antarctica has been named after him.

## Session V: Benefits to Medicine, Medical Technology and Biotechnology

This session will provide information on applications of space technology to medicine, medical research and health care. Examples will show how space technology has been instrumental in establishing a flow of information, ideas, and technology between the physical and medical sciences, benefiting areas such as clinical screening and patient monitoring, intensive care technology, life support and waste management systems, and many more.

The session is chaired by Dr. Walton L. Jones, the Deputy NASA Director of Life Sciences at NASA Headquarters. Dr. Jones, a Fellow of the Aerospace Medical Association, was formerly Director of NASA's Human Factors Program in the Office of Advanced Research and Technology (OART) for 6 years. Prior to that, he served in the U. S. Navy as Naval Medical Officer, Flight Surgeon (1944), and Staff Surgeon. In 1960, he was designated Space Surgeon. Among Dr. Jones' numerous accomplishments while with the Navy's Bureau of Aeronautics and BuWeapons and as Aeromed Requirements and Equipment Director in the Bureau of Medicine and Surgery, are the initiation and development of the first high-temperature nylon (with Du Pont) for flight clothing, the development of the Navy's full pressure suit and its conversion for the Mercury Program, the aeromedical direction of the F111B escape capsule development, and specialized research with the X-15 aircraft followed by spaceflight crew training. Dr. Jones has published over 50 papers and presentations and has been honored with numerous awards by the Aerospace Medical Association, the Association of Military Surgeons, and other organizations.

## Session VI: Benefits to Telecommunications, Navigation, and Information Systems

The purpose of this session is to present examples of application of space-derived technology in the area of communications and navigation, as well as in other fields of information transfer. The use of communication and navigation satellites for civilian and commercial needs will be described, and the benefits of the space environment and space technology to improved information transfer and higher accuracy in ship and air traffic control will be highlighted.

Dr. Richard F. Filipowsky is chairman of the session. He is presently Professor of Telecommunications Technology at the College of Engineering at the University of South Florida. Before joining that university in 1970, Dr. Filipowsky worked 10 years for the IBM Corporation and, prior to that, for Westinghouse Electric Corporation in Baltimore. Born and educated in Vienna, Austria, where he received his M.S. and Ph.D. of Technical Sciences, he was associated with Telefunken Co. in Germany and Radio Marconi in Lisbon, Portugal. From 1950 to 1955, before coming to the U.S., he was Professor of Electronics at the Madras Institute of Technology in South India. Dr. Filipowsky is author and coauthor of 4 books, and more than 30 papers, and is holder of over 32 patents.

## Session VII: Meaning of Space to the Natural Sciences

Space exploration and space technology has proven to be of immeasurable benefit to the natural sciences. Recent progress and breakthroughs in sciences such as high-energy astronomy, selenology, cosmology, cometology, planetology and planetary astronomy are directly attributable to man's extension of his senses through his spaceflight capabilities. Purpose of the session is to discuss a few of the more intriguing aspects of these developments.

The chairman of the session, Dr. Ernst Stuhlinger, has achieved international fame in professional circles for his pioneering work on electric propulsion systems for space flight, and for his contributions in the field of space sciences. He is the Associate Director for Science of the NASA Marshall Space Flight Center at Huntsville, Alabama. Dr. Stuhlinger, who received his Ph.D. in Physics from the University of Tuebingen, Germany, in 1936, is a member of the former Peenemuende Rocket Development Center under Dr. Wernher von Braun. As a member of the famed "von Braun team," he came to the U.S. in 1946 and became an American citizen in 1955. After years of research on guided missiles at Fort Bliss, Texas, and work on high-altitude launchings of captured V-2's at White Sands Proving Grounds, N. Mex., he began his work on electric propulsion in the early 1950's. Before becoming Marshall's Associate Director for Science in 1968, Dr. Stuhlinger was Director of Space Sciences Laboratory of MSFC since its inception in 1960. He has authored over 150 papers and articles and a book on ion propulsion and is coeditor of two other books. He has been honored with numerous awards, among them two Hermann Oberth Awards and the NASA Medal for Exceptional Scientific Achievement.

## Session: VIII: Space Manufacturing Benefits

The manufacture of certain high-value products in space appears to offer one of the greatest potentials for the application of space technology. Studies in this new field suggest that biological materials and electronic crystals are likely to warrant the costs and be greatly improved by processing under the near-zero-gravity conditions of space. Many other ideas are also being considered, and research on them should provide future products. The papers in this session will provide an overview, an in-depth example, and a projection of the future for this field.

The session chairman is Dr. Leo Steg, General Manager of the Space Sciences Laboratory of General Electric Company (GE). Before joining GE in 1955, Dr. Steg was Assistant Professor of Mechanics and Materials at Cornell University and, prior to that, an Instructor in Mechanical Engineering at the University of Missouri. Dr. Steg, who was born in Vienna, Austria, holds a B.S. in Mechanical Engineering from the College of the City of New York, an M.S. in Mechanical Engineering from the University of Missouri, and a Ph.D. in Mechanics, Mathematics and Physics from Cornell University. He is the author of 20 papers.

## Session IX: Benefits to Future Power Generation and Energy Production

The purpose of this session is to discuss cleaner power production through space technology, fuel cell and thermionics technology applications, power distribution and future power production in space.

Dr. John B. Dicks, Jr., is session chairman. At present, he is Professor of Physics at the University of Tennessee Space Institute and President of J. B. Dicks and Associates. Dr. Dicks obtained his Ph.D. in Physics from Vanderbilt University in 1955. He has published 40 papers, largely in the field of magnetohydrodynamic power generation and energy conversion. Dr. Dicks is a member of the American Society of Mechanical Engineers (ASME) and various other professional societies, and an Associate Fellow of the American Institute of Astronautics and Aeronautics (AIAA).

## Session X: General Technology Utilization in the Public Sector

This session will emphasize selected areas of public interest and needs of society such as housing, transportation, power, education, etc., and attempt to answer those needs by applying aerospace technology.

The session is chaired by Frederick I. Ordway III, a Professor of Science and Technology Applications and the Head of the Science and Technology Applications and Evaluation Section at the University of Alabama in Huntsville, Research Institute, since 1967. Prior to that time, Mr. Ordway was associated with the General Astronautics Research Corporation, the NASA Marshall Space Flight Center, where he served as Chief of the Space Systems Branch, and the Army Ballistic Missile Agency, as Assistant to Director, Saturn Systems Office. Other former associations of Mr. Ordway include Republic Aviation Co. and Reaction Motors, Inc. Mr. Ordway has studied at Harvard University and at the Universities of Paris, Algiers, Barcelona, and Innsbruck, and at the Air University and the Industrial College of the Armed Forces. He has published numerous papers and books and is editor of several professional publications.

## Session XI: Social Benefits and International Cooperation Through Space

The purpose of this session is to emphasize the impact of the space program on human society in general, by presenting examples of its influence on social, cultural, and economic development. Papers will treat subjects such as the application of space science and technology to developing countries, earth applications of space technology in other countries, and status, prospects, and outlook of international cooperative space programs.

The chairmanship of the session is in the hands of Dr. Franco E. Fiorio, Scientific Counsellor of the Italian Embassy in Washington. Dr. Fiorio was born in Milan, Italy, and graduated in Mechanical Engineering at the Polytechnic of Milan in 1934. In 1937, he received his Ph.D. in Aeroballistics at Turin Polytechnic. Dr. Fiorio served in the Italian Air Force for 23 years, retiring in 1957 as a Colonel and Head of Technical Services. From 1949 till 1955, he worked as Technical Assistant to the Air Attaché in the Italian Embassy in Washington. Since 1959, Dr. Fiorio is a member of the Italian Delegation to the United Nations General Assembly and, since 1958, the Italian delegate in the U.N. Committee for the Peaceful Uses of Outer Space. He is also Scientific Advisor of the Italian Permanent Mission to the United Nations in New York and Chairman of the Working Group on Remote Sensing of the Earth of the United Nations. A member of several American professional societies, Dr. Fiorio was a cofounder of the Allied Group for Aerospace Research and Development (AGARD) of the North Atlantic Treaty Organization (NATO), Consul General of the Republic of San Marino in the U.S. from 1957 till 1968, the Head of the Italian Delegation at the International Telecommunications Satellite Consortium (INTELSAT) Preparatory Conference and the Deputy Head of the delegation at the INTELSAT Plenipotentiary Conference of 1969. He has authored more than 200 papers on space research and implications and the Italian version of the book "Effects of Nuclear Weapons."

# WELCOME AND INTRODUCTION TO ASSEMBLY

By Dr. Wernher von Braun
Deputy Associate Administrator (Planning)
National Aeronautics and Space Administration
Washington, D. C.

In May of this year, when it still cost 6 cents to mail a letter, I was pleased to observe a new series of stamps that was issued on the now popular subject of ecology. They were entitled: SAVE OUR SOIL; SAVE OUR CITIES; SAVE OUR WATER; and SAVE OUR AIR.

All four stamps had in common one portion of their design: a view of earth from deep in space. That view is now familiar to people the world over -- the view that caught everyone's imagination when all of us were able to share for the first time the sight that greeted the eyes of Frank Borman and his Apollo VIII crew when they made the first flight around the moon.

It seems particularly appropriate that this photograph has become a widely recognized symbol of the deepening interest in protecting our fragile home planet — so beautiful and yet so vulnerable, as viewed from space.

It would seem almost self-evident that the newfound ability to observe the entire globe synoptically from space has given much of the impetus to the present deep concern over ecological problems.

But the view from space, important as it is as a symbol and a rallying point, is actually far more than that. The new tools and techniques that space exploration has given us could hardly have arrived at a more opportune time. Whereas a few years ago it was only the Rachel Carsons and a few other voices crying in the wilderness, today the concerned persons number in the millions.

And there are other concerns as well, also earthly, but asked more often by persons who feel the space program is not, if I may use a current catch word, relevant. These are the people who often ask whether we are not spending too much on space and not enough on urgent problems at home. When so many are unemployed, they say, and when hunger, sickness, urban decay, and other problems are crying out for solution, how can we spend all those billions on space?

Others feel we worship the god of technology at the expense of compassion for our fellow men. They affirm, with the deepest sincerity, that we should turn away from the "dehumanizing" pursuit of science and technology.

These questions arise from mankind's noblest emotions — love, compassion, and concern for fellow men. Many persons feel strongly that the human needs and the problems of a troubled society must come ahead of the "spectacular" feats of landing men on the moon.

They do not deny it was exciting to see astronauts walking on the moon for the first time, but now that it has been done, why do it any more? Think of all we could do with the money in feeding the hungry, finding a cure for cancer, or even conquering the common cold!

I think all persons of good will everywhere agree that these are valuable, important, and indeed urgent goals to pursue. But the assumption that science, technology and space exploration are irrelevant seems to me to be an incredibly myopic point of view. Far from worshiping technology, we look upon it as a tool to achieve human goals. And space exploration, which involves technology over the widest possible range of disciplines, can help alleviate some of the very problems critics hold to be most important to society and the individual.

Still, those of us whose lives are inseparably caught up with technology may have a tendency to take certain things for granted. We know of its capabilities and its benefits, and we assume that everyone everywhere shares in this knowledge. Unfortunately, that just does not happen to be so.

Therefore, I ask you to bear with me as I recount some of the new tools of space technology that will begin to see widespread use in the seventies. Although there will be many items with which this audience has more than passing familiarity, I mention them because I believe it is extremely urgent that the general public be given an opportunity to gain a similar familiarity.

Many of our most urgent problems today are global in nature. If we are to maintain earth as a livable dwelling place for mankind, we must learn to view it as a whole. We must understand that our existence depends on a delicate balance of nature, and that this balance includes not only all of mankind but of all living things. We must know the intricate relationships and reactions between this planet and a dynamic solar system, particularly the sun. To obtain this knowledge and understanding is one of the prime objectives of the National Aeronautics and Space Administration (NASA) space program. It requires a sustained effort to develop the science and technology and the space vehicles to reveal what man's limited senses and capabilities cannot perceive unaided. In this perspective, we can see that our vision has been broadened to encompass nothing less than the conservation of the whole of earth for all of mankind.

Our preliminary observations, made as early as the manned Mercury orbits in 1962, and the earlier Television and Infrared Observation Satellite (Tiros), weather satellites, led to the concept of instrumented spacecraft capable of locating and monitoring the earth's resources, including not only its geology, land areas, and seas, but its atmosphere as well. The growth of the world's population with its attendant increasing demands for food, potable water, shelter, transportation, and communications, means that all nations must ultimately join in managing the use and replenishment of our natural resources. An expanding population also poses its own pollution and waste problems by overburdening the natural ability of the ecological system to absorb them without upsetting its balance.

In both instances, the space program offers capabilities directly aiding in the solution of these problems by means of instrumented spacecraft that can identify and monitor resources and pollution synoptically on a global basis.

We cannot navigate our way through the sea of problems and obstacles to achieve mankind's broad objectives without the aid of new instruments and tools and vehicles. We have learned yet another lesson from space flight in both manned and unmanned spacecraft: what we can see with our unaided eyes is only about 1 percent of total reality. The other 99 percent of the electromagnetic spectrum is invisible, and cannot be sensed by human beings except by instruments designed for the purpose. When we realize that our earth's environment is so directly and vitally affected by radiations and particles from outer space that we require precise measurements of the energy poured out by the sun into this environment in order to understand the mechanism of its dynamic reactions, we begin to appreciate the importance of these instruments and of the human intellect that devises them.

The space program has taught us many things about our environment, but serious gaps remain in our body of essential knowledge. We have no idea, for example, how stable our present climate is, or how much additional atmospheric and water pollution can be tolerated without altering it drastically. Such knowledge comes to us in many ways — from sensors in spacecraft orbiting the Earth, from space probes investigating the atmospheres of Mars and Venus, from observations and photographs made by astronauts, and from analysis of extraterrestrial material brought back from lunar missions.

We have learned that Mars and Venus have atmospheres and environments quite different from Earth's and from each other. If we can gain an understanding of why they are so different, what processes caused them to evolve along different lines, and what processes control the temperatures and compositions of their atmospheres, then we may better understand and manage earth's atmosphere.

If all continues to go well, we expect to be learning a great deal about Mars during the next 3 months from Mariner IX (launched May 30, 1971), which went into orbit around the Red Planet November 14, 1971. As it circles the planet, the spacecraft will map 70 percent of Mars' surface, and televise back to Earth a record of the planet's topography. Mariner IX is a very sophisticated spacecraft, and it will give us about 12 times more planetary data than all previous Mariner missions combined.

However, I must also mention that the Soviet Union is making even more extensive efforts in planetary exploration than we are. Two very large Russian spacecraft are arriving at Mars very soon after ours. Each of the two is nearly five times as large as Mariner IX, which suggests that the Soviets may be planning a soft-landing of instruments on the surface. If they do so, they will be accomplishing a feat that we will not be able to duplicate for 3 more years.

This does not mean that we need to push the panic button, but it is well to remind ourselves that the Soviet Union is moving strongly ahead in space.

Last year, and so far this year, they have made three times as many successful launches as we have. It is true they suffered a tragic setback with the loss of three cosmonauts returning to earth from their Salyut orbiting laboratory. But the laboratory itself was successful, and again, this was an endeavor we will not be able to attempt until 1973. One final point on this subject is that, although their gross national product is only about half as large as ours, they are spending as much on space research as we are. Thus, in relative terms, they are making a space effort that is roughly twice ours.

That is one of the reasons it is so important that we get the maximum return from each space dollar. To do this, we are proposing a Space Shuttle, which is essentially a two-stage launch vehicle with one or more stages recoverable and reusable. Part rocket and part airplane, it takes off vertically and lands like an airliner — horizontally, under piloted control. The upper stage will take up to orbit as much as 50 000 lb of payload for as little as $100 per pound — less than one-tenth of the current figure.

Having the Space Shuttle available will permit us to do both manned and unmanned space missions that today we cannot even consider. Scientific personnel other than astronauts could be rotated to and from a Space Station with relative ease. All manner of supplies and equipment could accompany them.

With unmanned automated satellites, the savings offered by the Shuttle should be really remarkable. It now takes 6 to 8 years to develop a payload for flight. Then, if it does not go into proper orbit, or fails in any way to operate correctly, all that work and money go down the spout — of perhaps I should say, up the spout.

In a recent study, NASA examined 131 payload failures. Of these, 78 would have been eliminated in a shuttle type of launch. Furthermore, the other 53 could have been returned to earth, fixed, and then placed back in orbit. These figures speak for themselves.

Thus, as you can see, the Space Shuttle is a key element in our space program of the future.

Meanwhile, there are matters of more immediate importance where space technology can be usefully applied. Three major areas include earth phenomena observations, communications by satellite, and meteorology. In each of these areas, NASA is making a strong effort to develop the spacecraft and systems, the techniques and operational experience whereby space can be used in the service of mankind. A large part of the effort is shared by many countries and people throughout the world.

In each of these areas there is a potential for improving the conditions of life. One of NASA's most exciting space technology applications is the Earth Resources Technology Satellite (ERTS). It promises to aid in food production and the efficient management of valuable resources.

This satellite is designed to take inventory and monitor the condition of forests and crops, detecting disease and insect infestations, locate natural resources of fresh water and minerals, spot pollution of waterways and the air, supply data on oceanography and geography, even aid in urban planning among its many diverse tasks.

The first satellite is due to be launched next year, the second in 1973 for a period of testing sensors, techniques, and data interpretation before operational vehicles and systems can be built and turned over to user agencies. For the following generation of satellites NASA will continue to experiment and develop the technology further.

Intercontinental color television programs via satellite have become commonplace, but these are only the beginning of what will be done in coming years. Even so, satellites have already greatly reduced the cost of telephone and teletype services, including those of competing undersea cables. Techniques for spot broadcasting to selected sites, such as isolated communities, are now being developed. We also envision conferences by participants sitting in their own offices in different cities, together with the images in color of other conferences. The same would be possible for medical consultation between doctors in separate countries. The possibilities are nearly endless. The idea is to "move electrons around instead of people."

Ironically, the undeveloped countries without large investments in wires and cables stand to reap the full benefits of advanced satellite communications before their more technologically sophisticated neighbors. We and our more advanced fellow nations have heavy commitments in outdated communications systems, such as the telephone. These tend to act as a drag on attempts to replace them with more advanced equipment.

India will be one of the first countries in which some of these possibilities will be demonstrated. There is an understanding between NASA and the Indian Government to work with that country in demonstrating nationwide coverage of educational television via satellite. Starting about the calendar year 1973, we plan to make time available to the Indian people for about 4 to 6 hours a day using the UHF channel on our Application Technology Satellite (ATS-F).

At Madras, Bombay, Ahmadabad, Delhi, and Calcutta, the Indian Government will install relatively large receiving stations to rebroadcast to receivers in metropolitan areas. But in outlying districts, which will be chosen all over the country, more moderate-sized receivers will be used for distribution to viewing sets in the communities.

Approximately 5000 receivers over the whole country will be emplaced for this experiment, and the Indian Government has estimated that it may eventually serve as many as 20 million people.

The potential impact of educational television on this scale is obvious. It is equally obvious that the same techniques could be applied to increase the general educational levels of the other countries very rapidly — particularly some of the new and emerging nations around the world.

Another familiar satellite service are the meteorological cloud-cover scanners that have been operating since 1960. Satellites and weather are inherently global systems. It was in the spring of that year that NASA placed this revolutionary new tool in orbit to monitor the world's weather systems. Over the years since, the space agency has improved the technology and developed more advanced weather satellite systems. Every nation in the world can benefit from the U.S. meteorological service simply by installing an automatic readout station and signaling the satellite overhead to transmit photographs of the cloud cover. More than 50 countries are using the system to view the daily weather patterns over their territories and adjacent lands.

Again, present weather satellite service, like communications, is in its early stages. The goal is to perfect long-range forecasting of up to 2 week or more. Currently we can track large storms and give timely warning to prevent loss of lives and restrict property damage. Satellite tracking of the huge storm, Camille, saved hundreds, perhaps thousands, of lives in the Gulf States in 1969.

I have omitted mention of space program "spin-off" and the economic effects of developing large research and development programs. These are not inconsequential. Whole areas have been raised economically and in their level of education by NASA's programs. Those of you who are here know that Huntsville is a case in point. As an old Huntsville resident myself, I seem to recall that this modern and progressive city was once famed mostly as the watercress capital of the world.

Space research has advanced medical science by probing into various fields of physics, biochemistry, and others. One of our scientists, for example, specializing in space radiation, devised and demonstrated a theory that helps explain the source of uncontrolled malignant growth and indicates shortcuts to the development of chemical countermeasures against cancer. Thousands of medical and other developments useful to man can be cited. Space research is especially valuable in this respect because it must press forward on all frontiers of knowledge, and advances in one often bring advances in other fields.

In summary, then, this nation must continue responding to new challenges in the years ahead and not in simplistic terms of "either/or." We must press forward both in the space program and here on earth. These are not mutually exclusive, but mutually supporting enterprises.

Many benefits are now being realized, but we can expect far greater returns as increasingly sophisticated devices go into service. Data from space regarding our earth, its oceans, its resources, and its agriculture will be obtained and applied in the words of the Space Act of 1958, "for the benefit of all mankind."

# WELCOME AND INTRODUCTION TO ASSEMBLY (Continued)

By Dr. Eberhard Rees
Director, George C. Marshall Space Flight Center
NASA — Marshall Space Flight Center, Alabama

If this should happen to be your first visit to the Deep South, I believe you will return home with a fresh new concept of the characteristics of this region because of its progress in science, technology, and industry.

You will find that traditional southern hospitality is never out of season. You will always receive a warmhearted welcome here in winter or in summer.

Your hosts, the members of HATS, are to be commended for undertaking such an ambitious project of bringing space down to earth, and for bringing to all an account of its benefits. This serious undertaking gives evidence of their concern over the rising tide of criticism in recent years directed toward science, technology, and the space program.

There are, of course, those who carry the impression that the sole purpose of the nation's space program was to land men on the moon. Now that this has been achieved, these people favor severe, almost ruinous reduction of the space budget. Apollo XI was indeed a significant milestone in the exploration of space, because of the capability it represented. But it was only one aspect of this nation's broad program of peaceful exploration of the universe for the benefit of mankind as is mandated in the Space Act.

Now, NASA has, I think, been conscientious in carrying out the charter requirement that its activities be conducted openly, and that its many advances in science and technology be made available to all potential users. It is surprising to me to discover people who are not only uninformed, but who have misconceptions about the space program. Worse than this, it is saddening that they make misrepresentations about it to others.

Here are a few sentences, for example, from a letter to the editor in the October issue of the official publication of a national young men's organization. It reads — and these words are the letterwriter's — not mine:

"The recent moon shot marked another black page in the history of civilization. Four billion dollars were shot into space on another fruitless wild goose chase. As famous as the latest moon shot seems, while we squander these billions trying to find something of value on the moon, and then a way to bring it back to earth, we starve oceanographic research programs . . The space program is relatively unproductive and unnecessary at this time. We must face reality and take care of humanity's basic needs before building monuments to esoteric technology . . . "

This entire formidable undertaking must take its place beside a long register of corollary benefits. Quite contrary to the unfounded premise of our misguided letterwriter, man has indeed profited directly and substantially from the lunar venture. This will, I think, become increasingly evident as the Congress presentations unfold.

I am happy that the members of HATS have recognized the existence of misconceptions and misunderstandings about the benefits of space exploration, and are doing something about it. They have carved out a tremendous job for themselves. But they are not without resources. In fact, a sizable facet of their task is one of selection from a vast array of items for display within the time available. I seriously doubt whether such a weeklong conference on the benefits of space exploration could have been held a few short years ago. We entered the Space Age on faith and on the promise of potential benefits. But today those envisioned benefits and practical applications of space technology have become so much more visible and evident that it would be virtually impossible to discuss them within the time allotted.

To convey an idea as to the magnitudes of which I speak — the Marshall Center alone has contributed some 10 000 innovations derived over a period of 9 years and have not been restricted to just a few narrow fields but rather have been quite broad in scope. Helpful contributions, for example, have been made in the fields of aerodynamics, bioscience, chemistry, communications, computers, electronics, photography, holography, lasers, materials, and so on. Specific, well-documented accounts of advances within these fields are available for those who may desire them.

Now, I should point out here that the sizable output mentioned flowed from but one center. The other NASA centers, too, have contributed a substantial number of advances in technology to a growing list.

I note from the program that HATS has arranged an impressive array of conference chairmen and participants, representing NASA, industry, and universities. This combination of government-science-industry talent has been duly credited with the achievements made in the exploration of space thus far. I believe we can depend upon that same combination to present the proven benefits of space technology in a thorough and convincing manner, not only during this week's conference, but in the days ahead. Because of their deep experience, you are assured of an interesting and informative Congress.

Let me say once more that we are most happy that you could be here, and I hope that each of you will return home and assume an apostle's role in conveying to others the information you receive at this Congress.

# WELCOME AND INTRODUCTION TO ASSEMBLY (Concluded)

By Major General Edwin I. Donley
Commanding General
U.S. Army Missile Command

After looking over the HATS program, I think I was the sole uniformed member of the Defense Establishment who had an opportunity to address the Congress, which hopes to place on public record the benefits to mankind of the space resources and exploration. I testify not as a sinner but as a convert. Certainly, the Army's missile programs and indeed all of our aerodefense programs have been one of the prime beneficiaries of the advanced technology that resulted from the impetus of the massive space effort of the last decade.

Because I believe that we need an on-going space program, I have a few personal comments to make, and if they sound critical they are not meant to be. I hope they are accepted in the spirit in which they are offered. I certainly intend constructive comment.

These are not easy times for the military or space programs or, indeed, for any government program or institution which depends upon public understanding and support to accomplish great and wonderful deeds through the application of advanced technology. Unfortunately, great and wonderful deeds of that kind involve expenditures of great and wonderful sums of money. Certainly, the theme for the conference is appropriate, and the purpose for holding the meeting is very commendable. Also, we can agree that the public does need more information about the direct and potential benefits accruing from its space program.

I think the public is asking, "What is in it for us, and what does space mean to us here on earth?" That is a simple pair of questions! But only a simple man would try to give a simple answer to those questions, and perhaps they are not even fair, but they are being asked and they have always been asked. You can almost see Ferdinand and Isabella and all those at the Spanish court listening as Columbus described the wonders of his first great voyage. You can just about hear them saying, "What is in it for us?" Now Columbus talked of gold and spices, new lands, and many other things. Columbus — if we can believe the accounts — was a skillful presenter, and it was only years later, when people got tired of hearing him say, "I told you so," when many began to think he was a little bit tiresome. I suppose Columbus talked of a lot of things but, unfortunately for him, those who listened heard only the word "gold." As it turned out, there was just not that much gold. By the time he made his second voyage to the New World, he found he had a rebellion on his hands because there was not enough gold to be found to make everyone rich, and, from then on, it was all downhill. Columbus died a broken man but not before crowds had followed his sons through the streets chanting, "There go the sons of the admiral of the mosquitos; of he who discovered lands of vanity and illusions, of the grave and ruin of Spanish gentlemen." But within 30 years following Columbus' first voyage, history tells of a great renewal of human spirit that was underway. Columbus, of course, by that time had been in his grave for many years. But I suggest that you might keep Columbus in mind as you read this publication.

You may be approaching these reports with the premise that "to know us is to love us" — that, surely, once the public understands the things that the space program can do for them, then suddenly, there will be a clear public mandate to get all of the space program. Perhaps that is true, but I am not so sure. In today's climate, it is not so much a matter of what could or can be done, or how much it would cost or even if it is cost-effective. The overriding concern, it seems to me, is simply one of need. The question is not how do we go about this, but rather, do we need to do this at all. In my judgment, that is the attitude that shot down the SST. There simply were not enough people convinced that they really needed an airplane that would make the trip in half the time that they ever expected to make at all.

At a time when people can seriously ask, just as they are asking, "Do we really need an army?", those of you concerned with our future space programs must keep your eyes firmly fixed on the real mission; of what you really can do now and what you alone can do, and certainly, you need to speak out clearly on the need to do it. You have learned to sail the new ocean. Now, give us a few short reasons why you should make further voyages.

Transcribed from tape

# SESSION I

# MAN IN NEAR-EARTH SPACE – CONCEPTS, LOGISTICS, OPERATIONS

# UNMANNED SPACECRAFT FOR RESEARCH

By Dr. Carl D. Graves
Manager, Advanced Systems
TRW Systems Group

## Introduction

The remarkable achievements of the Apollo Lunar Exploration Program have tended to overshadow unmanned automated satellite flights. It is not always realized that spacecraft operating in earth orbit have already revolutionized global communication, maritime navigation and worldwide weather forecasting. These satellites, the result of NASA's Space Applications Program, are now vital links in a global network providing worldwide services which would not have yet been economically or technically feasible prior to the advent of near-earth space operations.

The Space Applications Program of NASA's defers in a fundamental way from its manned and scientific program. This difference is best characterized by the fact that the Space Applications Program has users or "customers." The users cover an enormous spectrum of our society ranging from Federal Government departments such as Interior, Commerce, and Agriculture to individuals and groups. Both the private sector and public sector are represented, state and local governments as well as airlines and shipping companies. In the last decade we have barely begun to exploit the potential of space applications for our society. As you will hear in the later sessions of this conference, the next decade promises to be a rewarding one, and the returns from our space investment will be substantial.

## Space Applications

The two major parts of NASA's Space Applications Program are Communication and Navigation (Comm/Nav) satellites, and Earth Observations satellites. Table 1 lists the seven major applications in each of these categories. The Comm/Nav applications are characterized by the transfer of information from earth to satellite or satellite to earth to be used for a variety of purposes ranging from transmission of telephone and television programs to the precise location of aircraft and ships. On the other hand, the earth observation applications all involve looking down at the earth with sensors onboard the satellite. The sensor data are then transmitted to earth where they are processed so as to obtain useful information. In both cases the customers shape both the character and goals of the applications indicated.

Interestingly, the two application categories besides having different objectives are characterized in general by two different types of satellite orbits. As illustrated in Figure 1, the Comm/Nav satellites are in what we call earth synchronous or geostationary orbits at an altitude of approximately 22 000 miles above the equator. In this particular orbit the satellite's period of rotation is identical to or synchronous with the period of the earth's rotation. Consequently, the same geographical part of the earth remains constantly in "view" of the satellite antennas. By virtue of this unique geometric relationship to the earth, a satellite in synchronous equatorial orbit has operational possibilities not easily realized by other means. It has a constant line of sight for communication to any point on the visible 43 percent of the earth's surface. The ability to connect a single point on the earth to myriads of others that can be simply equipped, and are not necessarily accessible by other means, has an unusual spectrum of applications. The inherent advantages of a satellite system are important for most communication activities and some navigational demands. On the other hand, the earth observation satellites generally have a requirement for observing the whole earth (including the polar regions) on a daily or weekly basis. Furthermore, the sensors onboard the spacecraft usually require a low altitude and a constant angle of sunlight reflected off the earth into the sensors so as to maximize their performance. Consequently most earth observation missions require a polar orbiting satellite so as to get repetitive coverage of the whole earth and to maintain a constant sun angle. This type of orbit is called "sun synchronous."

During the later sessions of this symposium you will hear many presentations on these applications satellites. By way of introduction to these later sessions I would like to give you an overview of these application missions with particular attention paid to how these satellites benefit you and some of the prospects for the future. Perhaps as I review these missions you will discover for yourselves other applications where data from these satellites would be of help to you or your profession or your community.

## Comm/Nav Applications

The first application on our Comm/Nav list (Table 1) are point-to-point communications satellites. These satellites provide transmission links for terrestrial communication systems. As illustrated in Figure 2, these satellites provide communication between ground stations in various countries (International Telecommunications Satellite Consortium [INTELSAT I, II, III]) and will shortly provide communication between various cities within a country or between two adjoining countries. Figure 3 gives the projected growth of telephone voice channels during the next decade. This growth in communication needs is now economically satisfied by the use of satellite systems and will result in reduced telephone bills for you and me. Furthermore, television communication for specialized needs can be provided by these satellites. Organizations with major offices spread over a large country or over the globe could use such circuits for many purposes including, for example, management and engineering meetings, television tours of major projects, introduction of new products and services, and instruction of sales and maintenance personnel at field locations. Other potential applications include the rapidly growing field of point-to-point data transmission. Long-distance interconnection of computers and other data-processing equipment is being considered for such purposes as:

1. Information-retrieval systems
    a. Travel reservations
    b. Technical literature
    c. Stock quotations
    d. Medical information
2. Government administrative systems
    a. Social Security system
    b. Internal Revenue Service
    c. Motor vehicle bureaus
3. Time-shared data-processing systems
    a. Remote computing
    b. Remote manipulation of text
4. Management information systems
    a. Inventory control
    b. Production control
5. Financial information systems
6. Consumer-data services
7. Remote typesetting

The above gives you a partial listing of the potential applications of this type of communication satellites. Perhaps you can see others.

Another major communication satellite application is the distribution and retrieval of information. Potential users of this type of application in the fields of education, health services, law enforcement and libraries have already been identified. Figure 4 illustrates a medical and health information network. Data from medical libraries, schools, and hospitals could be readily available to a medical center remote from these facilities thus bringing us better and cheaper health services. Another example can be found in the field of education. Education in the U.S. is approaching a crisis where the key issues are cost and equality of educational opportunity. In the past 10 years the cost of education in the U.S. has risen by 160 percent to $70 billion. The student population has grown by 129 percent to 59 million students. Labor costs for education are greater than for any other major U.S. economic sector, with over 60 percent of the total expenditures going for the salaries of the instructors. Furthermore, equality of educational opportunities demands a much more unified standard of teaching and information. These factors point to the need of a unified national or regional educational system. The possibility of implementing an educational communication-satellite system is an extremely promising approach to solving the problem of linking large numbers of widely separated schools, libraries, and information centers.

Another major application of communication satellites is the direct broadcasting television. A satellite system could offer services to areas not presently covered by existing television networks, could extend the number of programs offered (more choice), and could offer special programs of particular significance to various regions of the world. Where wide-area coverage is needed for common program material, a satellite is much more economical of spectrum space than is a terrestrial system. To cover the U.S., for example, with typical stations having only a 50-mile radius takes about 10 channels to avoid interference between contiguous stations. The satellite can accomplish the same task with only one channel. This is a frequently overlooked advantage of satellites, and one that is not trivial, with spectrum space so valuable (Fig. 5).

The average number of channels available to a home receiver in the U.S. is only three. A satellite could profitably add several to this, either nationally or sectionally.

Conventional television stations have difficulty running profitably if they are devoted to educational and instructional programming in the broadcast sense. By extending the coverage cheaply, and thereby expanding the audience to whom the program material is directed, a satellite system appears to be natural for the complex of programming called public television. Included within this elusively defined class would be public-interest broadcasting, cultural and educational material, and even instruction in the scholastic sense. Such a system is technically possible in a variety of realizations. The obstacles are largely social and political. The question as to who would originate and control program material is, therefore, a thorny point.

Figure 6 illustrates the use of educational broadcast television to a country such as India with its vast population and lack of trained teachers. An experiment such as this will be tried with India, using NASA's Applications Technology Satellite (ATS) to be launched in the near future.

Figure 7 illustrates the use of satellites to relay data from various collection stations or platforms to a central processing facility. This type of data relay is particularly important where the data being taken are perishable. A data collection satellite can serve the purpose of complete, real-time, synoptic reporting by transmitting such data to a national or a regional processing center. Environment forecasting services alone are expected, for example, by 1975 to encompass 4100 land stations, 885 marine vessels and weather ships, 500 buoys, one or more satellites, and 4500 balloons. Approximately 6000 platforms provide agriculture and seismic data and approximately 10 000 platforms are envisioned for marine oceanographic and hydrological data. This large volume of data traffic makes the use of a satellite economical and provides for a far faster, more efficient service to the users of these data.

Figure 7 also illustrates the use of a satellite for air traffic control, collision control and navigation. This also will be a very important use of satellites in the next decade.

## Earth Observation Applications

The NASA Earth Observation Program is designed to improve methods of gathering data on our atmosphere and resources by remote sensing from automatic, earth-orbiting satellites. This program will deliver direct benefits to most Americans by improved weather forecasting and by helping to survey our limited natural resources, such as food, water, fish, minerals, and oil, and by contributing to their improved management. As a growing American population with greater expectations of a higher standard of living consumes more resources, occupies more living space, produces more waste, and puts more pressure on an already fragile earth environment, it becomes more important and finally crucial to manage the available resources effectively. The earth resources satellites are an essential tool, one of many in the national earth resources program whose objectives are to discover resources, improve the management of others, conserve those we have, and help to apply them for the public good.

The program is based upon several years of interagency cooperation. Many kinds of sensors for different users have been flown in aircraft over known test sites and their observations checked with the known surface vegetation and features. For several years, the Department of the Interior and the Department of Agriculture have been preparing requirements and testing applications. The Bureau of Land Management, custodian of the Nation's public domain, is interested in improved surveys of land use. The Bureau of Commercial Fisheries is measuring ocean color to find fish. The Forest Service wants better ways to survey forest infestations. The Bureau of Reclamation needs comprehensive water inventory data.

Visual photographic interpretation techniques are well established, although in photographs taken from aircraft the various species of flora tend to blend together. Crops and trees usually cannot be identified when viewed remotely in the visible portion of the spectrum. Tone and texture differences are revealed, however, when visual images are compared with images produced by sensors tuned to other wavelengths. Such multispectral sensing can identify and distinguish various species and varieties of plant life. Similar multispectral techniques may be used to distinguish healthy crops and trees from diseased or infected ones. Diseased or stressed plants reflect or emit different electromagnetic radiation than vigorous plants (Figs. 8 and 9).

When used together with visual imaging, data from new sensors, especially infrared, are expected to assist in a wide variety of interpretive studies, including identification of crop and timber species, analysis of crop vigor, estimation of crop production, and early detection of plant disease and stress over wide areas of farmland and forests. Remote sensing will simplify and make accurate the prediction of seasonal changes, and the assembling of statistical data on large-scale changes such as a function of planting, fertilization, and irrigation practices, and the gathering of inventory data.

Imagery from earth resources satellites can be used to construct land-use maps, make soil surveys, assess cropping practices and range conditions, and predict agricultural yields. Such crop information will become important as food production is increased to feed growing populations. Tomorrow's farm manager may be able to find out more about his operation from remote observations than by walking through his fields.

Similarly, public land managers can benefit from satellite observations of the public domain. Public lands and national parks and forests comprise 175 million acres in the U. S. and 289 million acres in Alaska. These lands are a resource base for the future. Today they are yielding income to the nation from oil, gas, forest products, and recreation. These lands also support about 7 million head of livestock and nearly 3 million big-game animals. Conservation of these resources helps support the $20 billion per year outdoor recreation industry.

The data-gathering potential of remote sensing from space will assist the Department of the Interior in administering these public lands and preserving their ecology. Studies of changing features or conditions such as grassland status and foraging patterns could be supported by synoptic observations from space. Environmental management can also benefit from timely and reliable, satellite-derived information on the distribution, health, and vigor of vegetation, and measurements of snow accumulation and glacier movement.

The geologists' chief information tool is the geological map which shows the distribution of rocks exposed at the earth's surface. Now, in addition to aerial photography, geologists will have available the big, synoptic view offered by remote sensing. These systematic space pictures will offer geologists a broad, integrating panorama from which they can select observables of interest for closeup looks by aircraft or ground parties. The advantage offered by observations from space is that aircraft or prospecting surveys can be directed to specific areas of interest.

Known relationships exist between concentrations of mineral and fuel resources and particular geologic features. Petroleum and metallic mineral deposits, for example, are frequently found near structural features such as folds or faults. In a space photograph, part of an entire mountain range could consist of a series of folded rocks, and in the series of folds might lie an anticline or dome which could yield oil. Aerial photographs have been used to identify such features, but pictures from orbital altitudes have proven superior for viewing the larger linear geologic features. A new fault system in southern California was first discovered in space photographs. Geologic features and faults are even more obvious in radar images than in visual pictures. Radar also penetrates clouds and haze, and can be used during nighttime (Figs. 10 and 11).

The conservation and utilization of water supplies is the responsibility of the Department of the Interior, of which the Survey is a part. No other resource commands a comparable percentage of departmental time, funds, and talents. Department water management activities include the mapping of water, studying its properties, predicting its behavior, impounding it, diverting it, desalinating it, and using it to create electricity, fish and wildlife habitats, and recreation areas. In addition, other agencies such as the National Weather Service also collect hydrological data.

Performance of these functions can be improved by the use of remote sensing. When earth resources satellites join this collection network, large-scale, repetitive imagery of water systems will supplement the point data already being taken. In addition, the network of automatic sensors in rivers and lakes will radio measurements to the satellites. The automatically repetitive feature alone is very valuable since hydrology is a data-dependent natural science, and its data are highly perishable. An operational system promises global, synoptic, repetitive, and real-time coverage of major aspects of the hydrologic cycle.

A new order of water resource inventory will be achievable. The available water in an entire river basin or lake system, for example, can be monitored repetitively. Repeated observations in the visual, infrared, and microwave regions of the spectrum can be made of snow, glaciers, and ice accumulations and melting patterns. These changes can be monitored during the seasons of the year over areas too large to survey by conventional means. More accurate predictions of runoff can be made. These forecasts, in turn, will enable hydrologists to better regulate the impounding and release of water in reservoirs. Programs such as flood control, irrigation, and power production, as well as water for urban and industrial consumption, can thus be better managed. Improving the basis for water management decisions will produce measurable economic benefits (Figs. 12 and 13).

In addition to reporting water inventories, remote sensing may help to reduce water losses. Underground fresh water is being lost to the sea. Aerial infrared detectors flown over the coast of Hawaii show 250 underground springs discharging fresh ground water into the ocean.

Cartographers are constantly searching for better, quicker, and more accurate ways to make maps. Of all the techniques at their disposal, aerial photography presently offers the best means of obtaining small-scale maps of large areas. Nevertheless, the U.S. Geological Survey reports that the complication of small-scale maps by current practices is a slow, laborious process of assembling thousands of observations, and scale maps available today are neither uniform nor timely. Fortunately, cartography is applying techniques developed in the space program which promise greater efficiencies. The process of assembling the thousands of aerial photographs into a mosaic of a large region is both long and costly. About 1 million such photographs would be required to make a photomosaic of an area the size of the U.S. From satellite altitudes, such a panorama of the U.S., would require only 400 pictures, could be assembled in a few weeks, and would cost only a fraction of the cost of aerial mosaics (Figs. 14 and 15).

Aerial photomosaics typically do not display uniform shadow patterns and texture. The sunlight angle is always changing throughout the duration of the aircraft's flight. Placed in an appropriate sun-synchronous orbit, a satellite is capable of producing pictures of the earth under virtually constant lighting conditions. In a sun-synchronous orbit, the satellite crosses the equator or any parallel of latitude at the same time each pass. Since the orbit plane of the satellite always maintains the same, fixed angle with respect to rays of sunlight, the illumination of ground features is consistent. Shadows in each adjacent satellite swath always point in the same direction. Images of large areas composed of pictures taken during many passes will display the same constant illumination. Satellite pictures are also geometrically superior to aircraft photographs of large areas because of the straight-down view. The distortions caused by oblique camera angles are eliminated. These features make possible automatic processing and interpretation techniques that are difficult or impossible to utilize working with aerial observations.

More than 70 percent of the earth's surface is covered by water. These broad expanses of the oceans, coupled with their dynamic nature, have made it impractical to undertake continuous broad-scale surveillance by conventional methods. Limited synoptic surveys have been conducted by Soviet, Japanese, and U.S. oceanographic vessels working in patterns over large areas, but their best efforts are necessarily limited to selected data points rather than the comprehensive coverage offered by satellite. Most of the world's oceans are never seen by man, while areas of special interest are checked only intermittently by ships or aircraft. Yet the oceans are the birthplace of the world's weather and must be monitored completely and repetitively before global weather forecasting can become a reality (Figs. 16 and 17).

Biological productivity of plankton and fish is perhaps the most important oceanic resource. In the years ahead, this resource must be monitored, conserved, and harvested with judgment. The oceans absorb surplus carbon dioxide in the atmosphere via phytoplankton which converts it to oxygen. The overload of industrially emitted carbon dioxide may already have saturated the ocean's capacity for conversion.

If enough of these planktonic resources are killed or their vigor impaired by spreading oil slicks or pollution films, world climate might be adversely affected. Our capacity for generating such slicks is increasing. If the Torrey Canyon tanker had been filled with herbicides instead of oil, all life in the North Sea would have been destroyed.

The temperature outlines of ocean currents and upwelling can be traced with infrared sensing. Since there is a correlation between ocean temperature and the location of large schools of fish, this type of data may prove valuable to the fishing industry. Satellite infrared imagery of the Gulf Stream has already confirmed the possibility of detecting differences in water temperature from space and of relating the temperature distributions to current patterns. Thermal mapping of ocean currents and sea ice, information vital to the future development of resources in Alaska and Northern Canada, has already been demonstrated. Surface temperature measurements help to identify locations of highest plankton concentration, the prime source of food for fish, suggesting preferred locations of the fish population.

Subtle gradations in ocean color which correlate with ocean flora may also indicate areas of high food content where fish are more likely to be found. Ocean color gradation in coastal areas may be used to produce updated hydrographic charts for use by navigators. Under the action of tides and currents, bottom contours are always changing faster than charts can record them. Depth contours in the mouth of the Colorado River have been prepared from color separations of space photography.

The sea state has been measured in experiments conducted from aircraft. Radar can illuminate the ocean's surface. The reflected energy produces different images corresponding to the height of the waves. Radar observations could be conducte on a 24-hour, all-weather basis since radar can pen trate clouds and storms, and does not depend upon sunlight. By measuring sea state, locating ice areas, and mapping favorable currents, remote sens ing can help to reroute ships at sea to reduce time at sea and improve efficiencies and profits.

Since the environment is a major resource, it should be treated and managed as the essential life-support resource which it is. More often, the environment has been relegated to the role of dump for the residues left over from conventional resource extraction and consumption operations. These residues pollute both water and air.

Water is polluted by oil, runoff from farmlands sprayed with chemical fertilizers and pesticides, effluent wastes, algae blooms fed by oversupplies of nutrients in organic wastes dumped into the water, and by heat. Many forms of water pollution can be monitored by satellite. The advantage offered by satellite sensing is that large areas of water or many small rivers or lakes, such as Minnesota's 10 000, can be monitored quickly, repetitively, and automatically. Water polluted by contact with polluted air, by the introduction of chemical fertilizers and pesticides, and the byproducts of domestic and industrial wastes will continue to pose serious problems.

Lake Erie, for example, receives 2.5 million tons of silt, sewage, and industrial effluents such as pickling acids from the steel mills and phosphate-based detergents each year. The biochemical oxygen demand of this overload has exhausted the supply of dissolved oxygen and the lake is now biologically dead. Other lakes are going the same way. Algae infestations which turn fresh water into green, sludgy soup, have occurred in such sewage basins as Lake Washington, Seattle, and Lake Tahoe, Nevada. Steam generating and nuclear power plants heat large volumes of water. Frequently, different pollutants are mixed together in one body of water.

To effectively monitor water pollution, a variety of hydrological characteristics must be measured: surface temperature gradients in lakes and streams, sedimentation dynamics, precipitation, lake and reservoir levels, and tonal colors (Fig. 18). Differences in water color may correlate with chemistry and vegetation such as plankton bloom and algae, thereby contributing to pollution studies. Polluted water may be warmer than adjacent unpolluted water and may be detected by infrared scanners.

Patterns of water flow are visible in aerial and space photography. By revealing flow features invisible from the ground, such pictures can be used to map and compute large-scale mixing patterns in bodies of water. Such patterns establish the basis for tracking and controlling pollutants.

Air pollution consists of toxic gases introduced into the atmosphere, carbon dioxide, particles such as fly ash, volcanic or radioactive dust, and aerosols used to disseminate pesticides. Distribution is more or less worldwide. These toxic gases attack the lungs and crops; pesticides attack reproduction. Combustion products from industrial processes and operation of aircraft and automotive engines introduce carbon monoxide, hydrocarbons, lead compounds, sulfur dioxide, and nitrogen oxides. Sufficient quantities of these gases can alter the chemical composition of localized atmospheres. Chemical changes alter the path through which sunlight falls to the surface and is reflected up to spaceborne sensors. The altered nature of the reflected sunlight may be the signature of such concentrations. The shape of this altered signal may also indicate the degree of toxicity.

Although local sources such as industrial plants and cities can probably be monitored adequately with ground detectors or aircraft, large regional distributions and cross-country movements of polluted air may best be monitored by satellites. What was a local problem until recently is fast becoming a regional problem. Now that Los Angeles smog is appearing over Arizona, perhaps Japanese pollution, notoriously heavy, may carry to our West Coast, or east-coast pollution may carry to Europe. Here again, the quick, repetitive, large-scale pictures from satellites can supplement data gathered by aircraft and ground detectors.

One of the most important long-range environmental tasks for remote sensing is to monitor the composition of the upper atmosphere worldwide. This thin film functions as a two-way value. It protects life on earth by filtering solar energy, allowing only enough to enter to nourish life. This film also passes heat radiated by the earth to space. Otherwise, the surface would heat up. Life exists and thrives because this global thermostat has been balanced for centuries. Now, however, since the industrial age has been converting fossil fuels to carbon dioxide, evidence is accumulating that the environmental balance is being altered by the changed composition of the upper atmosphere.

The effects of weather on human activities are so important that a national meteorological service is one of the first functional organizations established in every developing country. And because weather systems do not recognize national boundaries, there is a high degree of international cooperation in meteorological activities, even between nations which are otherwise less-than-friendly.

It is the large-scale nature of weather phenomena which has made the satellite such an important tool for meteorologists. Earth-orbiting satellites are able to observe weather systems, regularly, over oceans, deserts, the Arctic and other regions which are otherwise inaccessible to long-term human observations. Since man's ability to predict weather (wind, rain, etc.) is based on how well the initial state of the atmosphere is known, it follows that the large-scale observations available only from satellites should enhance the length and quality of weather forecasts. The close relationship between predictions and atmospheric observations is shown in Figure 19, which relates the increase in our predictive ability to the observational tools which made the predictions possible. Electronic computers are included to indicate that the meteorologist's ability to assimilate and understand great numbers of observations has been greatly increased at a very propitious time in meteorological history.

Since Napoleon's scientists first discovered the relationship between atmospheric pressure and the weather, meteorologists have sought better tools for measuring the characteristics of the atmosphere. The meteorological satellite has provided an unprecendented ability to observe the parameters on which accurate weather predictions can be based, and now there is a strong hope for a predictive ability for 14 days or longer. The advantages to the general public far exceed the cost of the satellites and their related systems. These satellites initially took pictures of clouds over the globe, and are now measuring the world's temperature distribution (at the surface and through the atmosphere to a height of more than 100 000 ft), snow distribution and ice distribution plus cloud-height patterns over the whole world. In addition they have provided a tremendous ability to relay weather information between observers and users of weather information between distant locations.

In a more specialized application, satellites are proving invaluable in monitoring severe storms, such as hurricanes. In the past, hurricanes often appeared on the horizon with little warning. Later, expensive aircraft reconnaissance was used to patrol areas of frequent hurricane occurrence, but often these patrols failed to locate storms which later caused great damage. With the advent of satellite observations came a capability to observe the hurricane belts of the tropics on a daily basis, and today the meteorologist is routinely aware of hurricane activities.

An example of satellite observations of hurricanes and tropical storms on September 14, 1967, is shown in Figure 20. This composite view of global weather was prepared from data gathered by the Environmental Science Services Administration (ESSA), a weather satellite operated by the Department of Commerce. Six hurricanes and two tropical storms can be identified and with this identification available it becomes possible to alert surface installations and aircraft operators in order to make precise measurements of the hurricane's movement and intensity.

Hurricane Beulah, located in the Caribbean a the time shown in Figure 20, was tracked by satelli on a daily basis until landfall at the Rio Grande Delt on September 20, 1967. Although this storm spawn over a hundred tornadoes and caused severe floodin damage and loss of life were minimized because of t advance warning provided to inhabitants of the area.

Besides providing information for use in hurricane advisories for the general public, satellites are helping meteorologists understand the dynamics of these storms. There is now more confidence in man's ability to eventually dissipate these storms before they become dangerous.

TABLE 1. EARTH-ORIENTED APPLICATIONS

| Communication and Navigation | Earth Observations |
|---|---|
| • Point to Point Communication | • Agriculture and Forestry |
| • Information Networking | • Geology and Mineral Resources |
| • Broadcasting | • Hydrology and Water Resources |
| • Data Relay | • Geography, Cartography and Cultural Resources |
| • Air Traffic Control | • Oceanography and Marine Resources |
| • Aircraft Collision Avoidance | • Environmental Quality |
| • Marine and Air Navigation | • Meteorology and Weather Prediction |

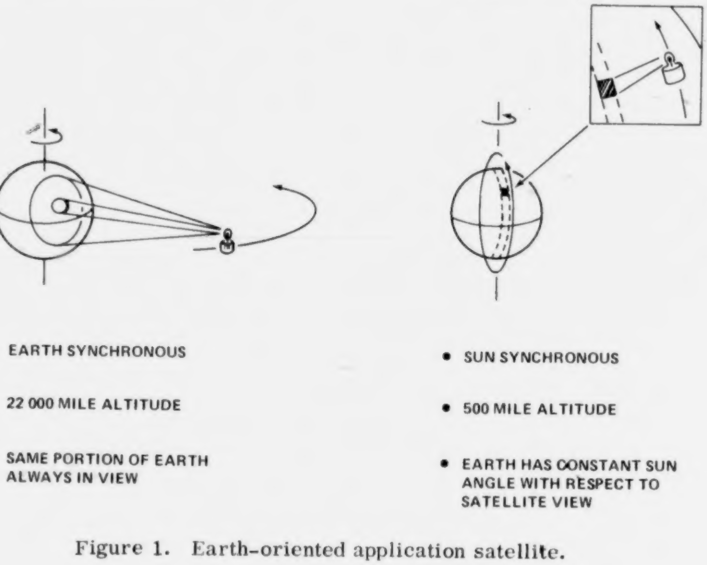

COMMUNICATION AND NAVIGATION SATELLITE
EARTH OBSERVATION SATELLITE
• EARTH SYNCHRONOUS
• 22 000 MILE ALTITUDE
• SAME PORTION OF EARTH ALWAYS IN VIEW
• SUN SYNCHRONOUS
• 500 MILE ALTITUDE
• EARTH HAS CONSTANT SUN ANGLE WITH RESPECT TO SATELLITE VIEW

Figure 1. Earth-oriented application satellite.

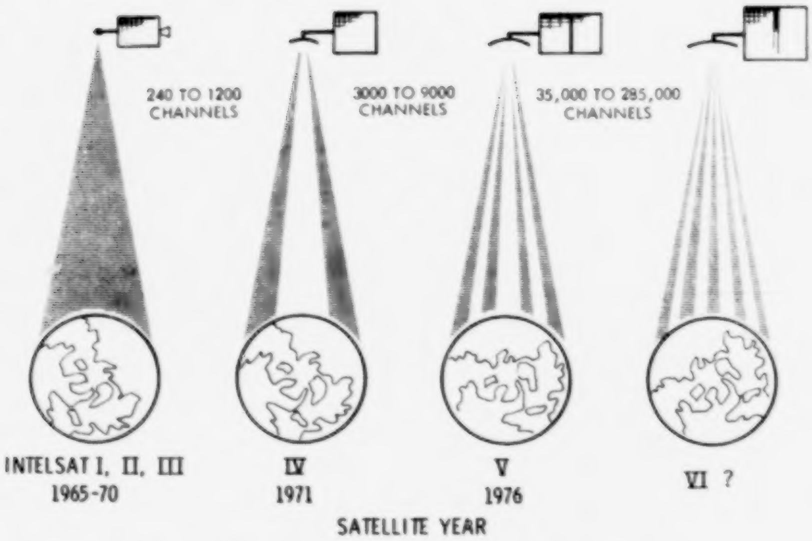

240 TO 1200 CHANNELS
3000 TO 9000 CHANNELS
35,000 TO 285,000 CHANNELS
INTELSAT I, II, III
1965-70
IV
1971
V
1976
VI ?
SATELLITE YEAR

Figure 2. Point-to-point communication satellites.

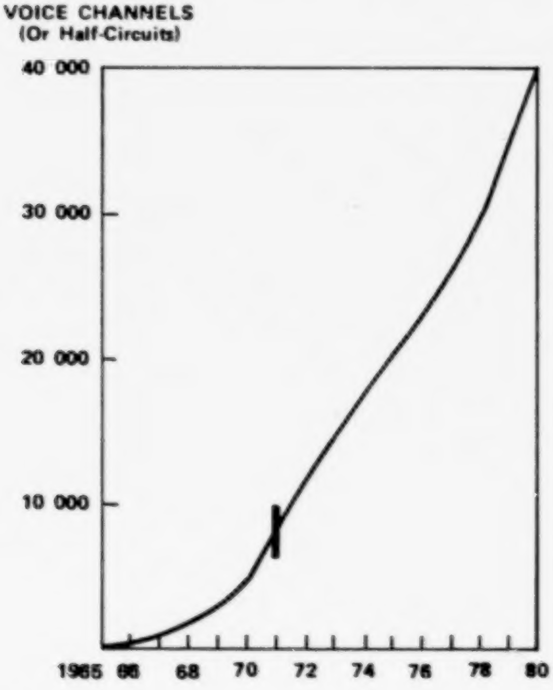


Figure 3. Projected growth of INTELSAT traffic.

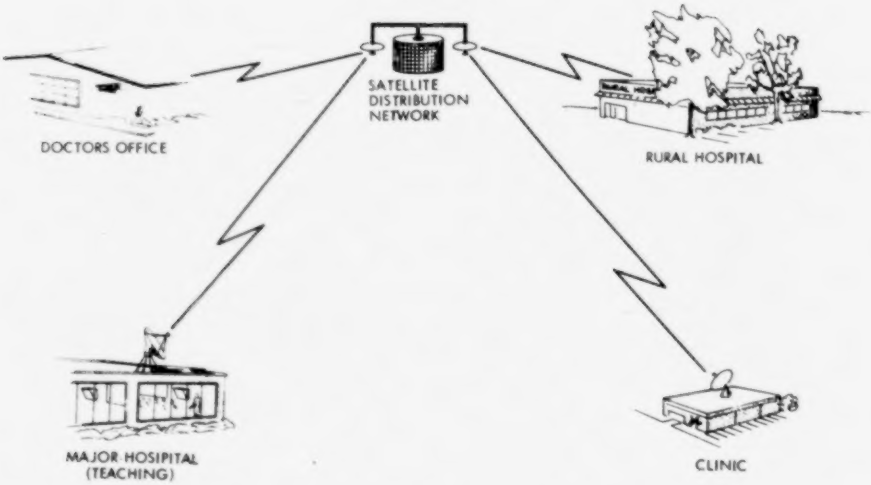

SATELLITE
DISTRIBUTION
NETWORK
DOCTORS OFFICE
RURAL HOSPITAL
MAJOR HOSPITAL
(TEACHING)
CLINIC

Figure 4. Conceptual medical and health information network.

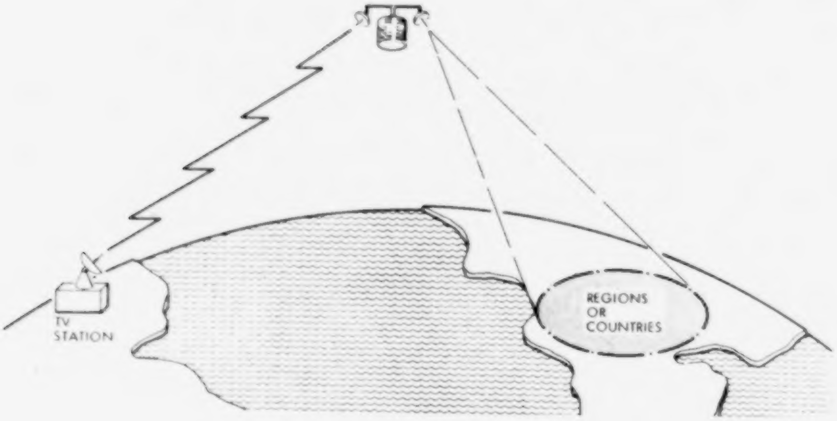

TV
STATION
REGIONS
OR
COUNTRIES

Figure 5. Direct broadcast television.

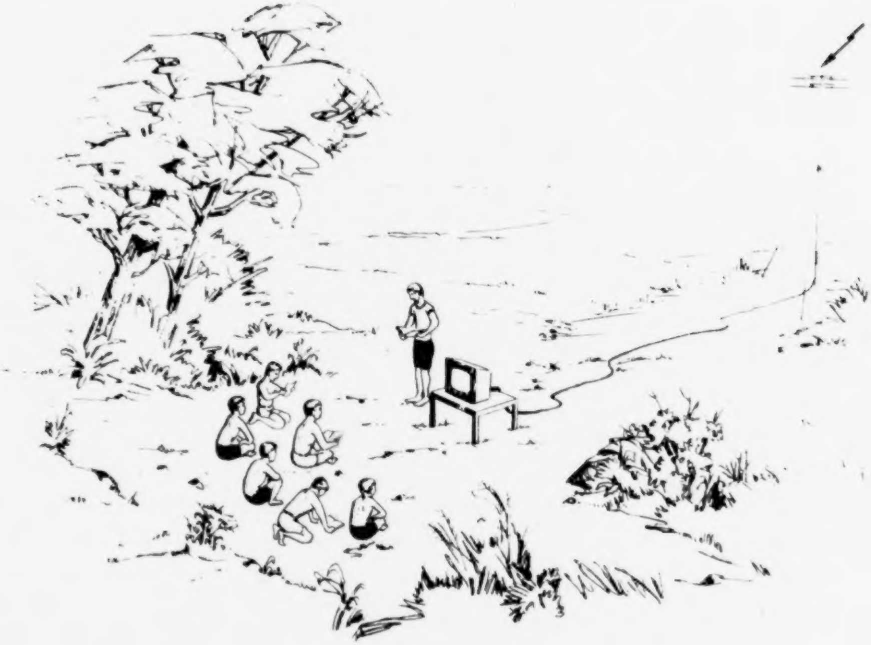


Figure 6. Educational broadcast television to India.

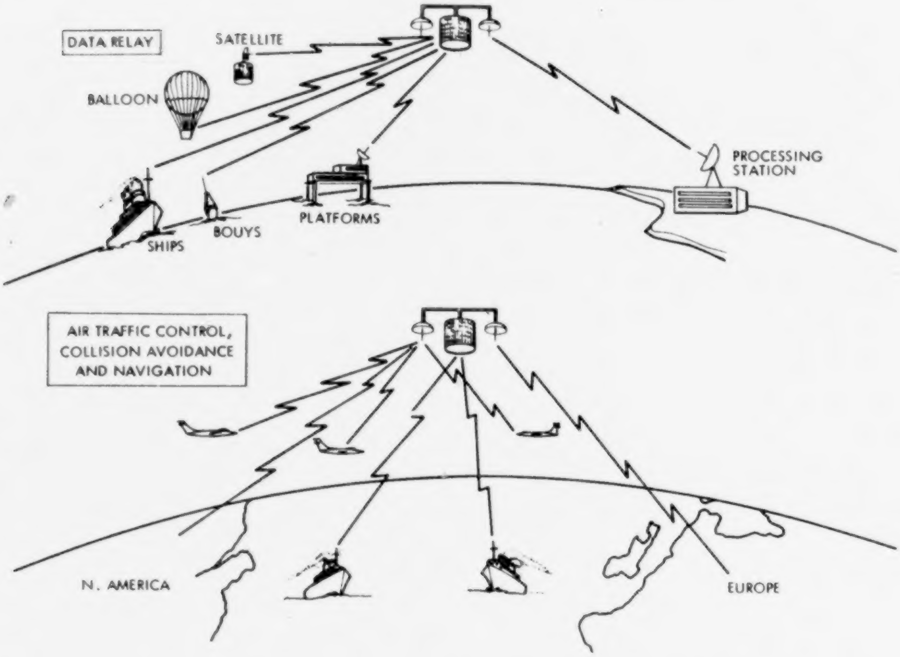

DATA RELAY
SATELLITE
BALLOON
SHIPS
BOUYS
PLATFORMS
PROCESSING STATION
AIR TRAFFIC CONTROL, COLLISION AVOIDANCE AND NAVIGATION
N. AMERICA
EUROPE

Figure 7. Satellite systems for data relay and navigation.

## Agriculture & Forestry

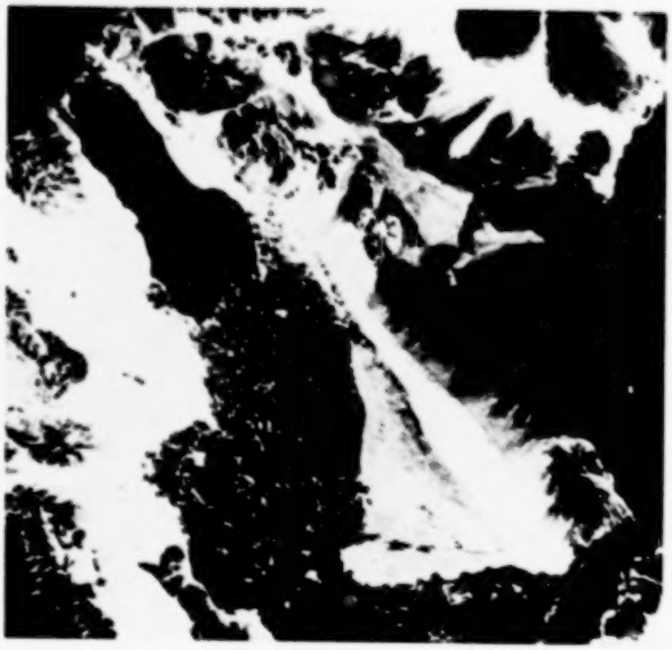


Figure 8. False-color photograph of Salton Sea (Apollo IX, March 1969) showing healthy vegetation in the Imperial Valley farmlands as red objects.

- Land use planning
- Crop irrigation
- Regional development
- Crop yield
- Grazing range management

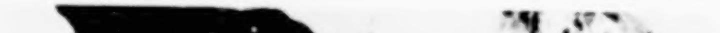
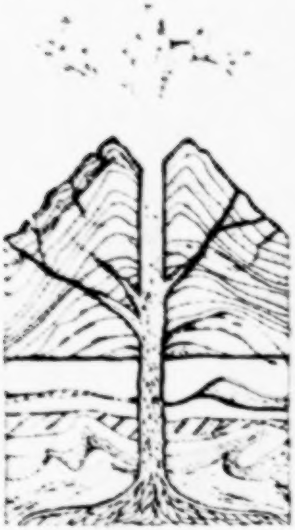


Figure 9. Apollo IX photograph of Salton Sea area used for construction of agricultural land-use map.

# Geology & Mineral



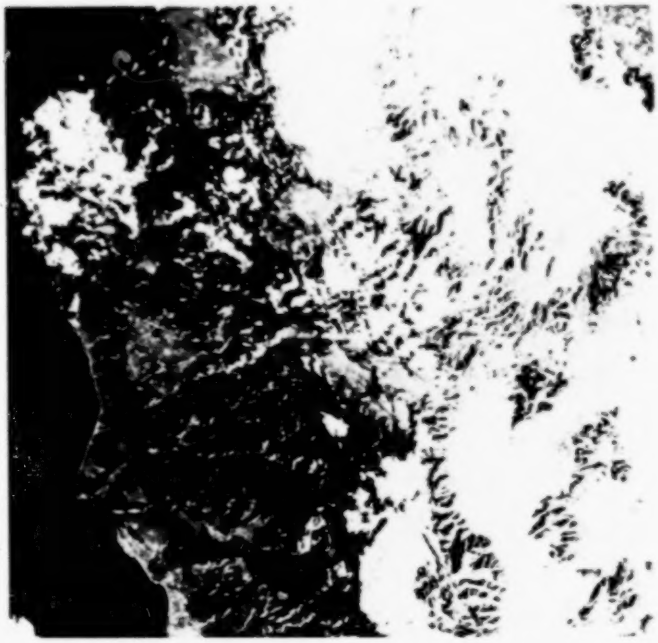


Figure 10. Apollo X photograph of Baja Peninsula area of California.

- Geologic mapping
- Geothermal & volcanic observation
- Fault & playa location

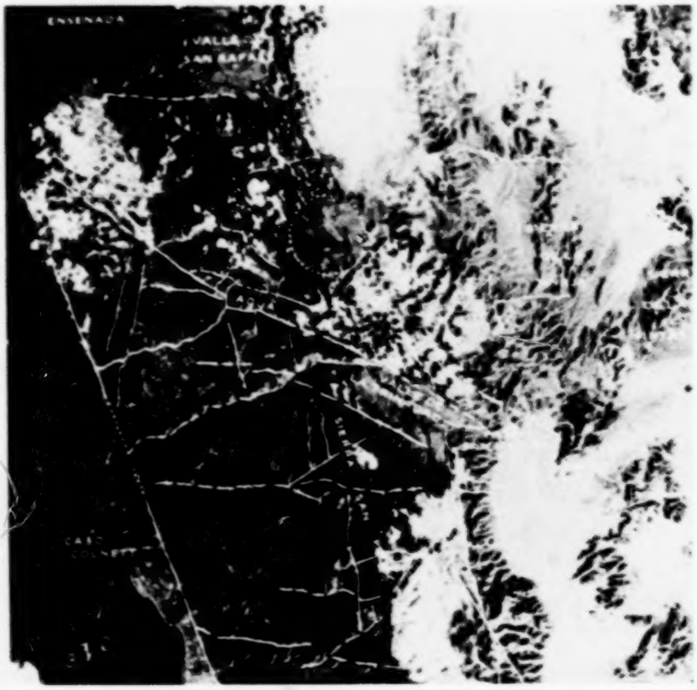


Figure 11. Photo interpretation showing faults, lineaments, and playas.

# Hydrology & Water

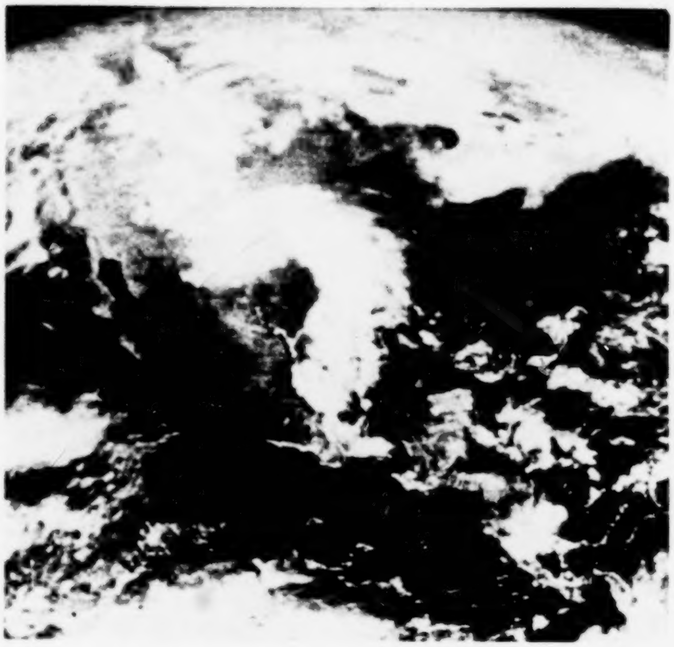


Figure 12. ATS-III photograph of California Sierras showing clouds and snow.

- Surface water mapping
- Watercourse location
- Drainage patterns
- Flood monitoring & prediction

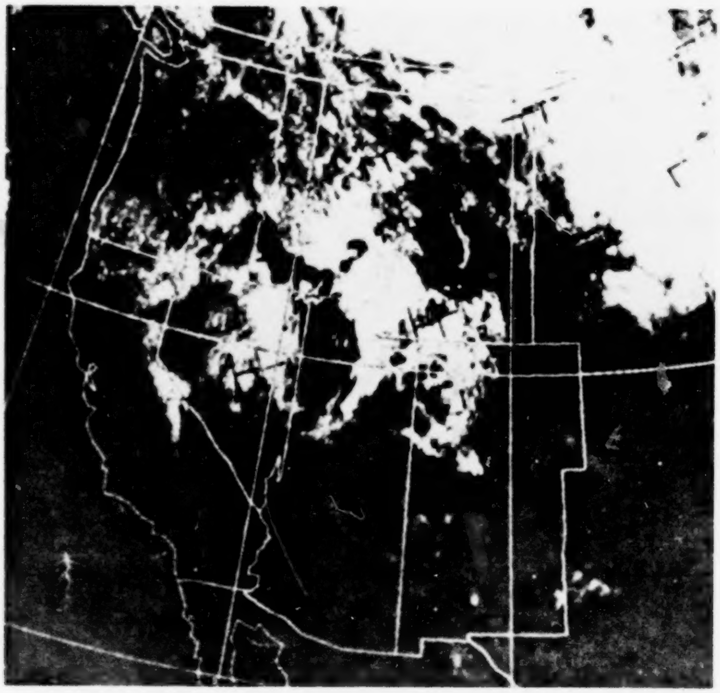
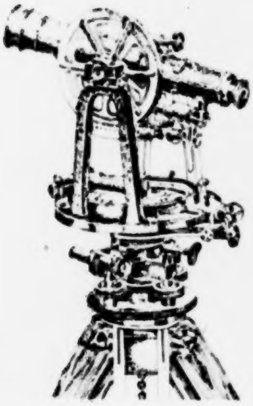


Figure 13. Map showing snow coverage, generated by ESSA from NASA photograph.

# Geography, Cartography & Cultural



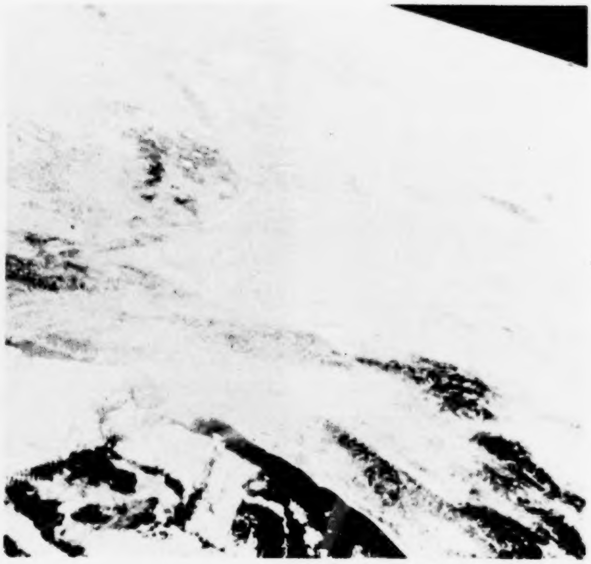


Figure 14. Apollo VII photograph of southern California showing smog plumes over the Los Angeles region.

- Air pollution monitoring
- Urban development
- Map updating

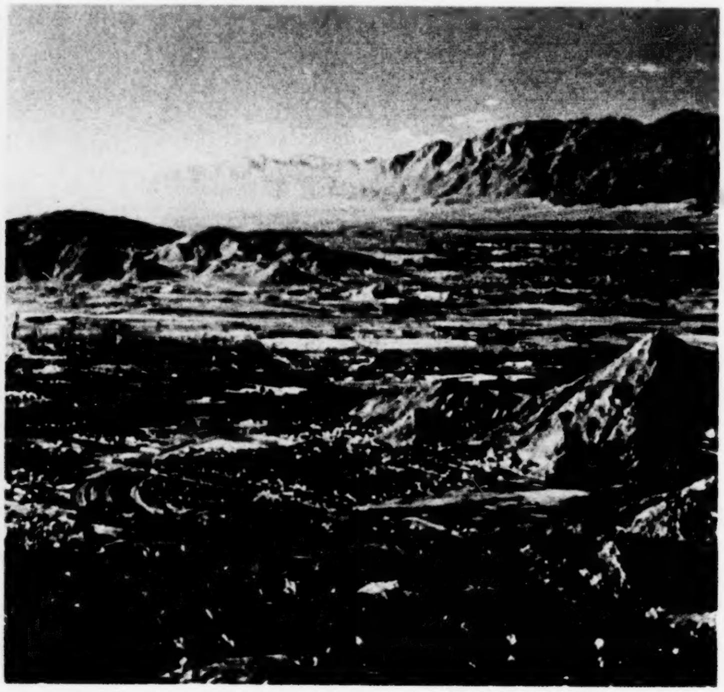


Figure 15. Multispectral photograph for pollution detection.

# Oceanology & Marine

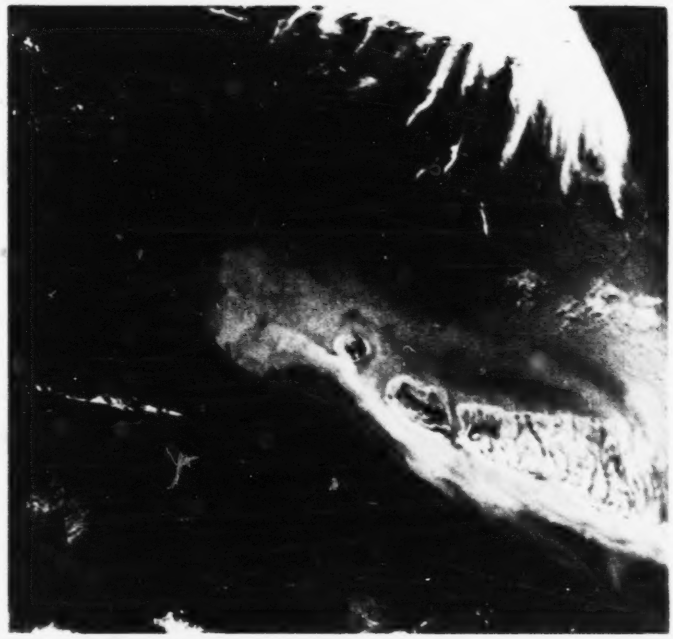


Figure 16. Apollo IX photograph of West Florida keys in natural color.

- Updated hydrographic charts
- Location of shipping hazards
- Location of fish feeding areas
- Monitoring of shoals and sandbanks

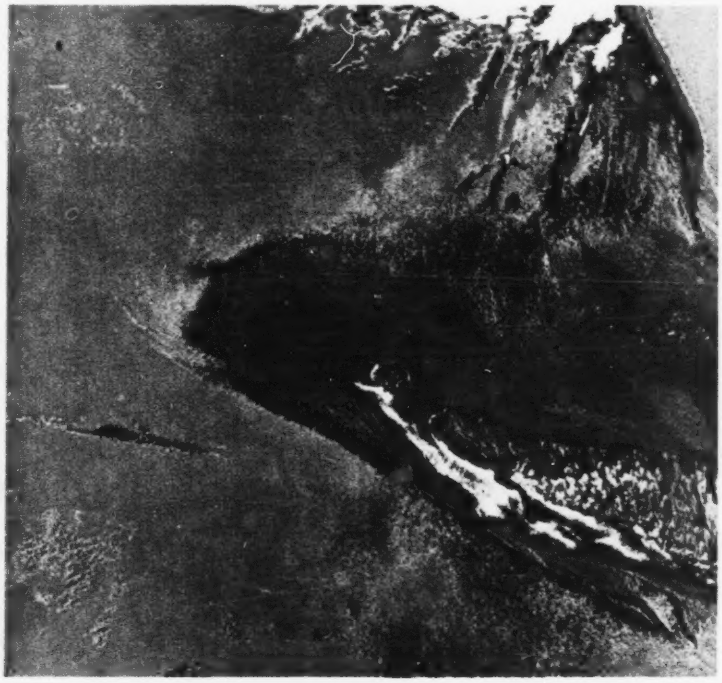


Figure 17. Interpretation of Figure 16 by NASA/Navoceano showing relative water depth to 10 fathoms in false color.

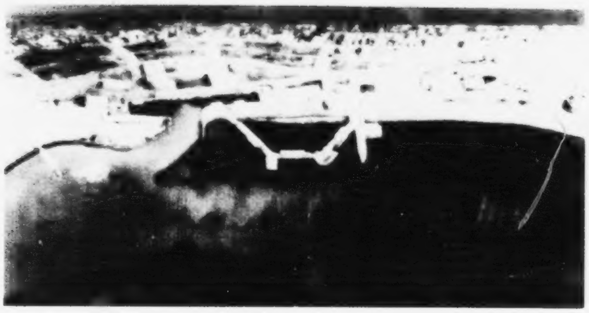


Figure 18. Thermal pollution monitoring.

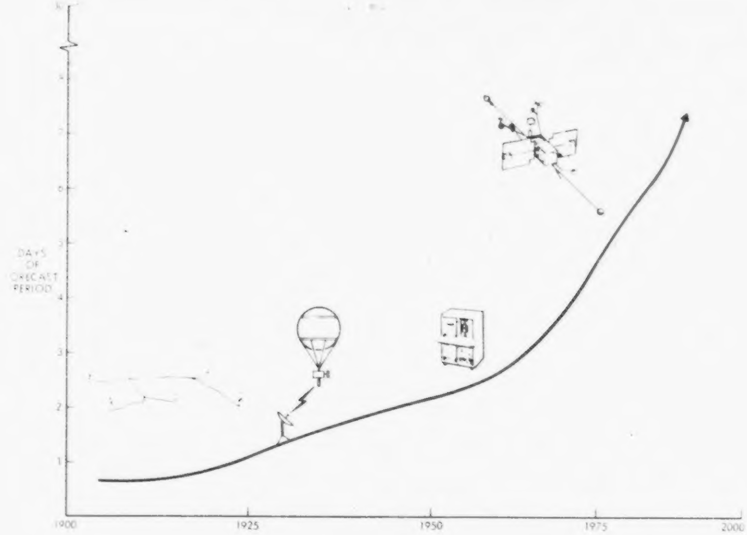


Figure 19. Progress in prediction of weather events.

OPAL
RUTH
SARAH
DORIA
CHLOE
T/S MONICA

Figure 20. ESSA V tracks eight major storms on September 14, 1967.

# SKYLAB

By George V. Butler
Program Manager, Skylab Advanced Systems
McDonnell Douglas Astronautics Company

## Introduction

In the next few days you are going to be overwhelmed with statistics on the myriad of past, present, and future benefits that mankind can expect from operations outside the earth's atmosphere. These benefits are real and offer, in my opinion, the only hope mankind has to perpetuate a habitable earth environment.

The previous speaker described unmanned data-gathering orbital systems and, I am sure, impressed you with the results to date and the potential yet to be exploited.

In my portion of this program I will describe how Skylab will operate, collecting data and using man's indispensable capability to observe, evaluate, make judgments, and adapt to changing situations.

I used the term exploitation a moment ago and want to emphasize that the space program is rapidly being transformed from basic experiments and explorations to useful operational exploitation. A major factor in achieving the necessary knowledge to solve mankind's problems will be the addition of trained scientists, doctors, and engineers as future orbiting working astronauts.

Skylab will be our country's first step in providing a long-term manned orbital capability.

## What Exactly Is Skylab?

Skylab is an experimental space station, designed to provide a comfortable shirtsleeve environment for a three-man crew for periods of up to 56 days in earth orbit. Figure 1 shows the Skylab "Cluster" as it will appear circling the earth. I will give you a brief description of the various elements that make up the cluster. Total design life of the cluster is 8 months, encompassing three separate manned visits.

Figure 2 shows the Command and Service Module. It is the ferry vehicle or "taxi," if you will, that takes the crew to and from the workshop. The astronauts will dock their spaceship to the Skylab in much the same manner as on the Apollo program where they docked and undocked with the lunar landing vehicle.

The Multiple Adapter (Fig. 3) provides — as its name implies — the docking port for the Command and Service Module. In addition, it houses the control and display panels for the solar and earth resources experiments, which I will discuss later.

The windmill-like apparatus on top of the cluster is one of the main experiments on Skylab. This telescope mount with its solar array panels is a solar observatory that will give solar physicists a look at the sun's activity free from the distortion caused by the earth's atmosphere. Figure 4 shows a more detailed view. While Skylab is photographing the sun from space, scientists here on earth will use ground-based telescopes to photograph the same areas of the sun for comparison of data.

The Airlock Module (Fig. 5) is the "nerve center" of the cluster. It serves as the Control and Distribution Center for all the electricity, the oxygen and nitrogen that the astronauts breathe, and the equipment for two-way voice communications between the Skylab and the ground control stations. The Airlock Module is equipped with a window or hatch from which the astronauts can exit the spacecraft and walk along a ladder to load and retrieve film used in the solar telescope cameras.

The largest section of the Skylab cluster is the Orbital Workshop (Fig. 6) with space equivalent to a small three-bedroom house. This 10 000 $ft^3$ two-story laboratory has been converted from the hydrogen tank of the third stage of the Saturn V rocket. It will serve as the primary living quarters and experiment operations area. The old cramped quarters and physical constraints associated with Gemini, Mercury, and Apollo will be a thing of the past. Individual rooms are provided for recreation, eating, bathroom-lavatory facilities, and sleeping. A home-type toilet will be particularly appreciated by the astronauts and will remove what has been one of the most irritating aspects of space travel. A shower that can be used in weightless space has been developed to be used onboard Skylab. A special interest to the ladies in the audience is the large amount of closet space available for storing food, water, clothing, trash bags, personal items, and various experiment equipment. The goal has been to create a very pleasant environment with many of the comforts of home.

There are some aspects of living in space that are unique and quite unusual to any that we find here on earth. For instance, in the weightlessness of space, there is no up or down — one may float around freely — so freely that:

- The astronauts will have to use "holddowns" to stay in position while eating at the dining room table, using the bathroom, and even while sleeping (Fig. 7).

- The normal commode found on the floor in most bathrooms will be located, as shown in Figure 8, on the side of the wall in Skylab for better utilization of available space.

- The bunks or sleeping restraints (Fig. 9) have also been placed on the wall, with the astronauts sleeping in a vertical position. These bag-type restraints merely keep the men from floating around while sleeping.

- Food will come prepackaged and placed on trays which are plugged into electrical outlets on the dining table for heating (Fig. 10). Menus will be very earthlike.

- The trash and waste material will be collected and placed into a large tank below the first floor by means of a special trap door located in the middle of the floor, as shown in Figure 11.

- The shower mentioned earlier is shown in Figure 12. It works on a suction principle drawing water over the body and into a tank.

The main work area is located on the second floor above the astronaut's living compartment (Fig. 13). To get to it, the weightless astronauts simply will float upstairs, using a fireman's pole for a guide rail.

## When Will Skylab Be Put in Orbit?

The Skylab is scheduled to be launched into a 270-mile orbit above the earth in 1973. A program mission profile is shown in Figure 14. The Skylab will be launched unmanned on a two-stage Saturn V rocket the same as used on the Apollo Program. The spacecraft will contain all the food, water, and oxygen needed for the entire mission. On the following day, after key systems have been turned on and working, the first three-man crew will ride into space aboard an Apollo Command and Service Module launched by the smaller Saturn IB vehicle. They will rendezvous with the Skylab cluster, transfer inside, and complete activation of all the systems. This first crew will spend 28 days in the workshop area conducting a wide range of medical, scientific, and technical experiments. At the end of the mission, the crew will return to the earth with an ocean landing and recovery, just like the Apollo lunar missions. Some 2 months later the three-man crew will visit the workshop for a 56-day period. After their return, and about a month later, the third three-man crew will visit the Skylab for an additional 56-day period. In all there will be a total of 140 manned days during the 8-month period.

## What Is the Skylab for?

I have briefly told you what the Skylab is and how we plan to place it into orbit. Now we get to the real heart of the program — what the Skylab is for.

Although the Skylab program has several objectives, they fall into two major categories. The first is centered around man's spaceflight capabilities over extended periods of time, so we will study and carefully monitor the astronauts. This will involve an assessment of man's operational capabilities as well as extensive biomedical experiments to determine the effect of long-term space activities on the human body (Fig. 15). The second major category is to conduct scientific experiments in which we will monitor and study the sun, the earth, and celestial space.

In all, there are more than 50 experiments onboard to accomplish the many and various objectives, with about one-third of them devoted to studying the biological effects of prolonged weightlessness on man. The astronauts will exercise regularly on a stationary bicycle as their physiological changes are carefully monitored. A reclining chair will whirl them around to determine their sensitivity to motion sickness. Urine samples will be collected and frozen daily for later analysis on earth to determine possible mineral losses from the bones. A device will be used to check out the cardiovascular system with measurements of the heart rate, temperature, and blood pressure being taken.

The important experiments for producing near-term benefits for man here on earth are the earth resources experiments (Fig. 16). Skylab has a number of sensors that are designed to record detailed information about our earth — not just from a scientific standpoint, but from a very practical standpoint. These sensors, for example, were chosen to detect specific information on types of soil and vegetation, crop vigor, and surface water conditions. From these data, inventories can be made of our natural and cultural resources. Skylab will collect and return more of this information than any other space program to date, adding greatly to the data expected from the unmanned Earth Resources Satellite (ERTS-A) to be launched by NASA in 1972.

NASA recently put out an announcement to several thousand potential users of the data that will be collected by Skylab. There were 701 proposals received from scientists, engineers, city planners, etc. They wanted information to solve practical, everyday problems such as city-growth planning, or estimating the snowfall during a winter season over the Rocky Mountains. The National Geological Survey Water Resources Division says that if they can tell the amount of snow 1 percent better than they are now able to — which is by tramping through the woods and pounding a rod in the snow and saying, "it's six feet deep" — If they can do this from Skylab 1 percent better, then the information is worth $10 million a year to them in managing water and electrical power operations. This is just one of many interesting and useful things that will be done with Skylab (Fig. 17).

As you might expect, in the 701 responses there were a few that turned out to be a little silly. One man, for example, requested a census of all of the black pepper in the world. He had a theory that black pepper was the source of all evil. Since he was from California, as I am, I have been intending to look him up to get a few more details on his theory — since I always thought it was women and booze.

What may turn out to have the greatest long-term benefits on Skylab are the solar experiments. Eight major solar instruments will constantly measure the sun in the extreme ultraviolet and X-ray portions of the electromagnetic spectrum and will record data as to the sun's activities (Fig. 18). We study the sun because it is the main source of energy that we have on earth, and we know very little about it. It is a complex thermonuclear reactor that we can observe and treat as a laboratory to unlock the real secrets of nuclear processes: so that those processes can be applied here on earth for development of future power systems. The astronauts will be able to select targets of scientific interest and actually point the telescopes. They will control and monitor the experiment operations in acquiring the data, including retrieval of the film (Fig. 19).

There are a number of other interesting experiments on Skylab:

- A small experimental space "manufacturing" facility is provided where the astronauts will do some casting and welding of dissimilar metals (Fig. 20). The absence of gravity and the high vacuum of space may provide a boon to certain manufacturing processes. Also, some technical or engineering tests will be made on various protective coatings, effects of contamination on parts of the Skylab from its own discharges, and space repair techniques.

- Small semiconductor crystals used today in electronics will be carried aloft (Fig. 21) to see if they grow better in space. If we can grow large crystals without built-in thermal or mechanical stresses, we will be able to build more reliable electronic equipment. This could result in better color television sets for you and me.

- We are also looking at the possibility of developing methods for producing vaccines for the medical community as one of the things that can be done more effectively in the zero gravity of space than we can do here on earth.

- A general objective of our Government's space program is to provide a platform for greater international cooperation and we do have, on Skylab, a French experiment containing an ultraviolet camera that will scan the heavens for new scientific information on the stars (Fig. 22). A second Skylab, if authorized, would be expected to have greater participation by many more foreign countries.

- Special interest to the younger generation is the plan NASA has set up to stimulate interest in science and technology by directly involving high school students in space research (Fig. 23). Information on Skylab has been sent to high schools throughout the country. A selection and awards process has been devised to reduce the total potential proposals to the final six which will actually be flown on Skylab (Fig. 24). Certain specifications (Fig. 25) have been established regarding size, weight, and astronaut time requirements, as well as criteria that will assure that the student's experiment is compatible with Skylab and will not affect the launch schedule. Money has been authorized to complete the selection process and to finance the development and integration of the six selected experiments into the Skylab spacecraft.

This concludes the basic overview of Skylab. I might emphasize that while Skylab is experimental in nature, it is expected to lead to operational systems that will provide a better understanding of the distribution and abundance of earth resources, the solar processes which will affect terrestrial weather and climate, and control of our environment. We can all expect to benefit from improved long-term management of the crucial earth resources required to keep the environment here on earth viable for mankind — now and in the future.

## What Will Skylab Cost?

Even though Skylab will cost about $2.5 billion, it will be spent over a 7-year period. Comparisons are dangerous and can be misleading, but I might compare this to a recent announcement in the agricultural area that the U.S. is prepared to spend $2.0 billion in 1972 alone to reduce the output of livestock feed grain. I would submit that the thousands of jobs created by the Skylab program over a 7-year period, plus the environmental and other direct research benefits we will obtain from its operations, make a very positive argument for the dollars expended. Placed in perspective the $2.5 billion does not seem so large. Even Snoopy benefits (Fig. 26).

A last closing thought about costs: our Federal Government is now spending 42 cents out of every tax dollar on human resources and about 1 cent for t Space Program — I am confident that by the end of this conference you will be as positive as I am that the taxpayer is getting more than his money's worth from the 1 cent spent on space programs such as Skylab.

## Will There Be a Second Skylab?

This depends on many things — timing, cost, solid requirements for data, and the capability of our astronauts to perform meaningful tasks over extended periods of time. If past experience is any guide, we can be sure that information gained from Skylab-A will produce a deluge of requests for additional information and new experiments.

You will be interested to know that the present Skylab program does contain a complete backup set of hardware. This backup Skylab will be shipped to the Kennedy Space Center in Florida, and readied for final acceptance and launch while Skylab-A is performing its mission.

Yes, there could be a second Skylab using the backup hardware and which would produce at least as much meaningful information as Skylab-A — and for roughly 25 percent of the cost of the first Skylab.

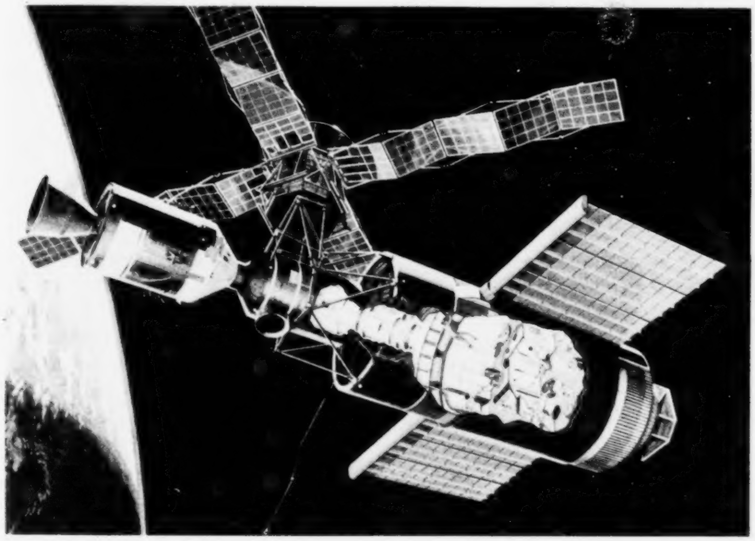


Figure 1. Skylab cluster.

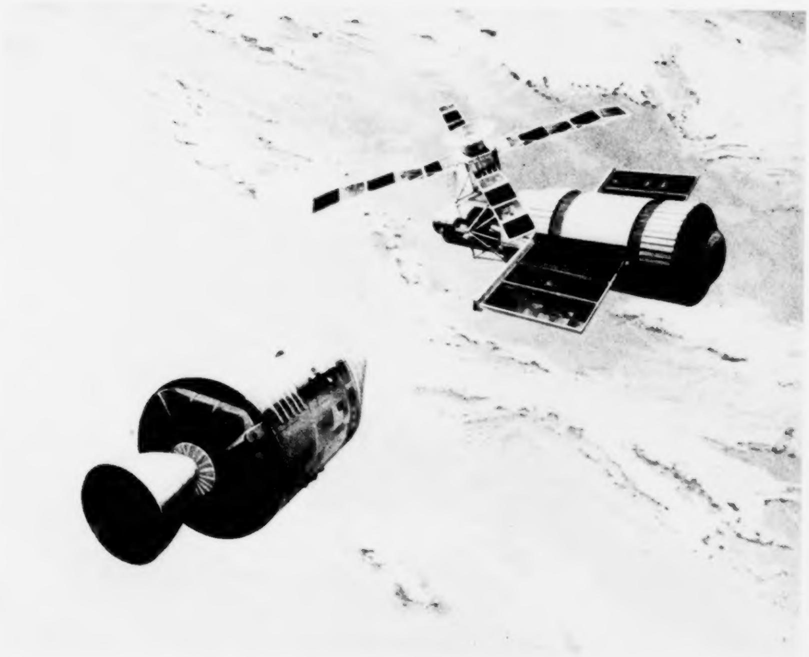


Figure 2. Command and Service Module.

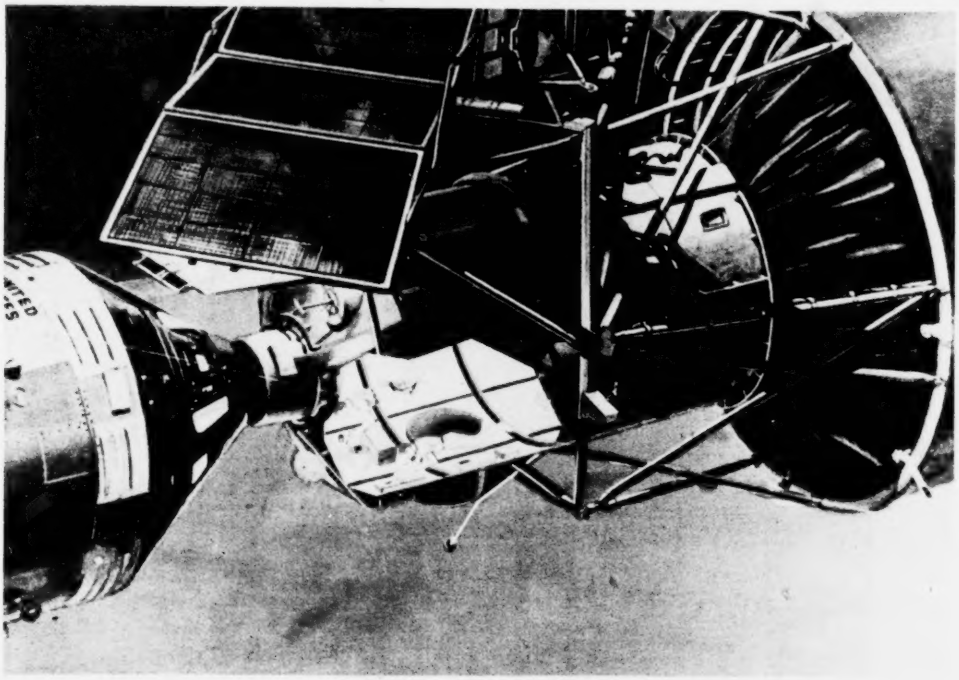


Figure 3. Multiple adapter.

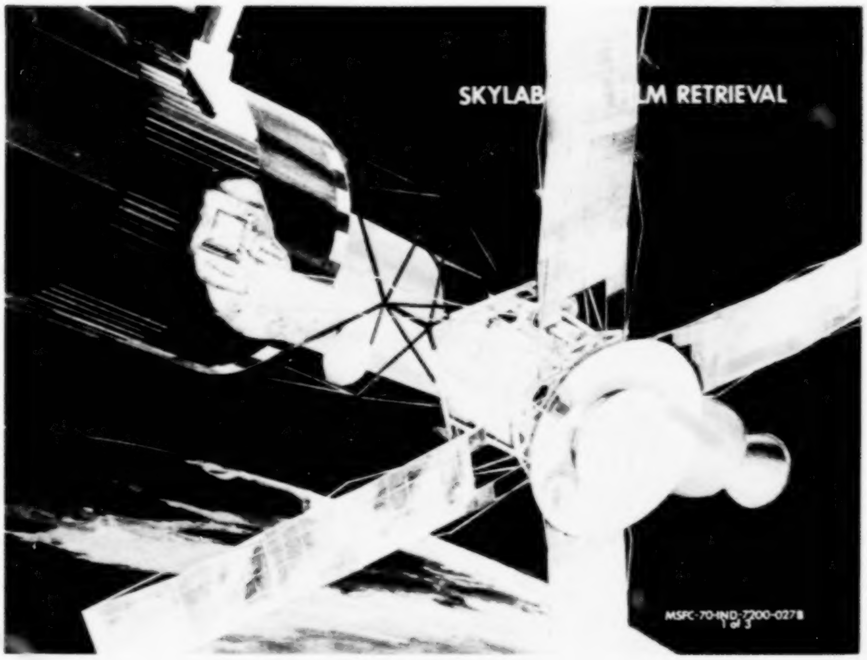

SKYLAB LM RETRIEVAL
MSFC-70-IND-7200-027B
1 of 3

Figure 4. Detailed view of telescope mount.

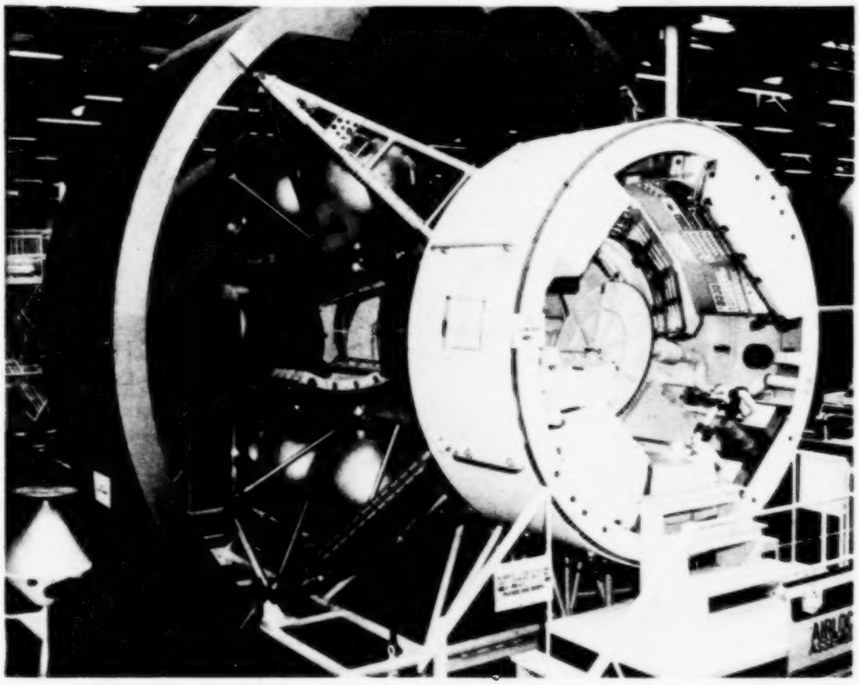


Figure 5. Airlock module.

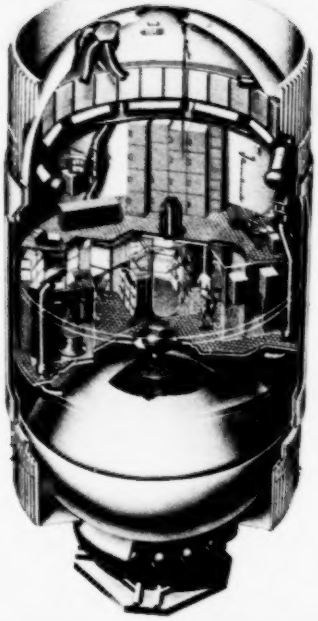


Figure 6. Orbital workshop.

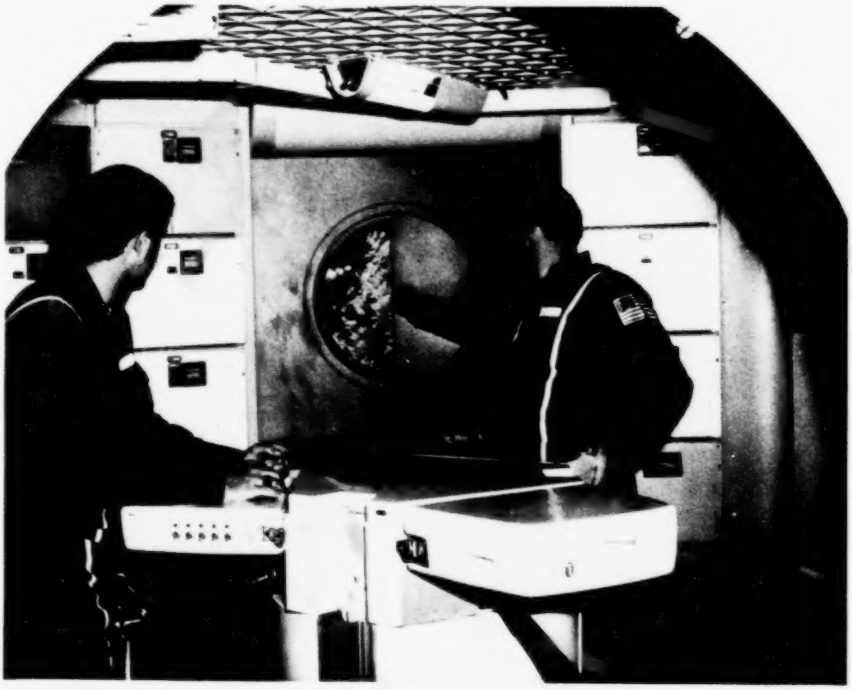


Figure 7. Astronauts positioned in dining area.

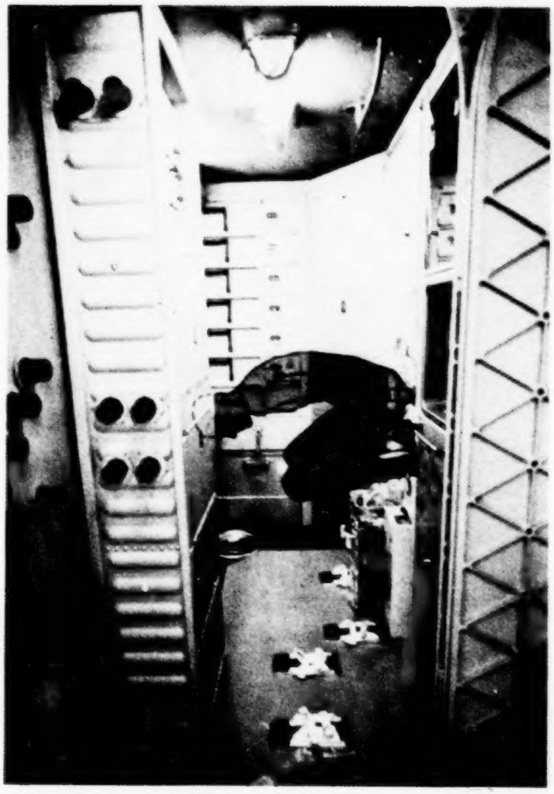


Figure 8. Bathroom.

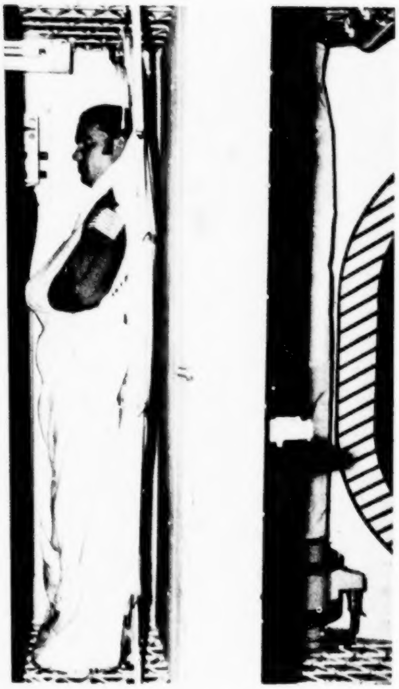


Figure 9. Bunks or sleeping restraints.

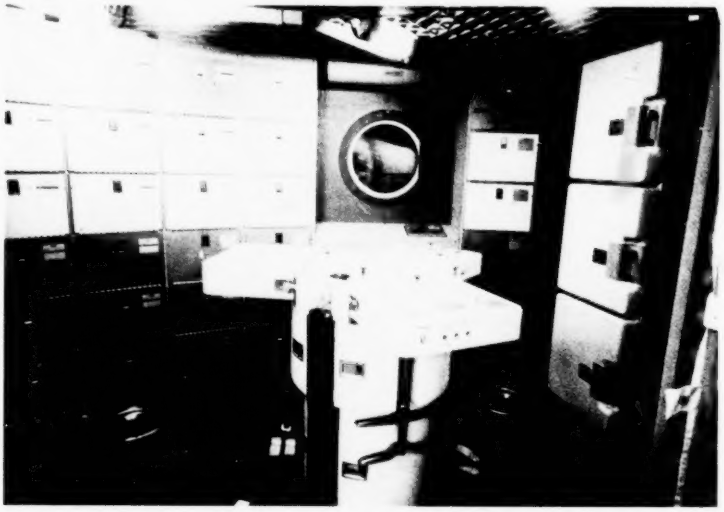


Figure 10. Dining area.

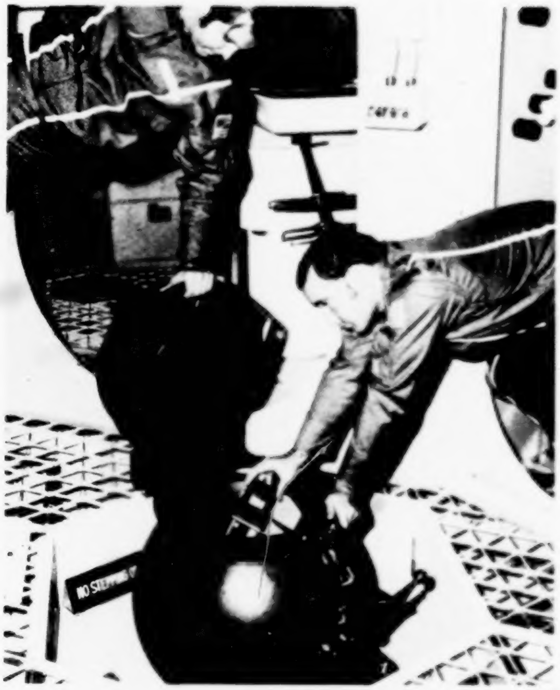

NO STEPPING O

Figure 11. Disposal of trash.

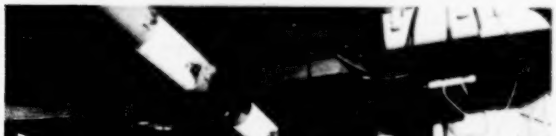


Figure 12. Shower.

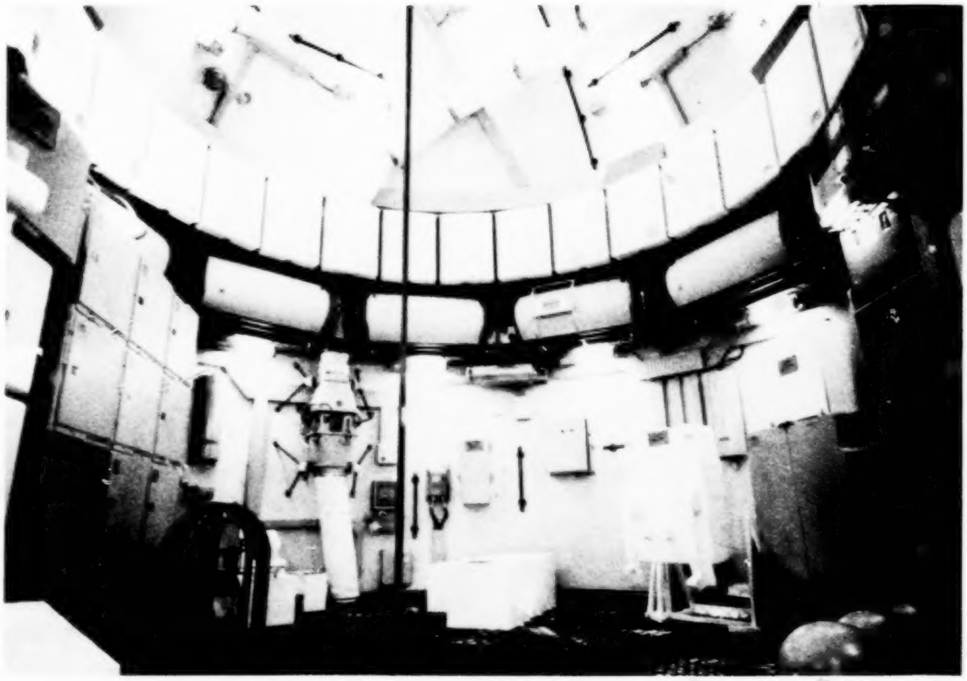


Figure 13. Main work area.

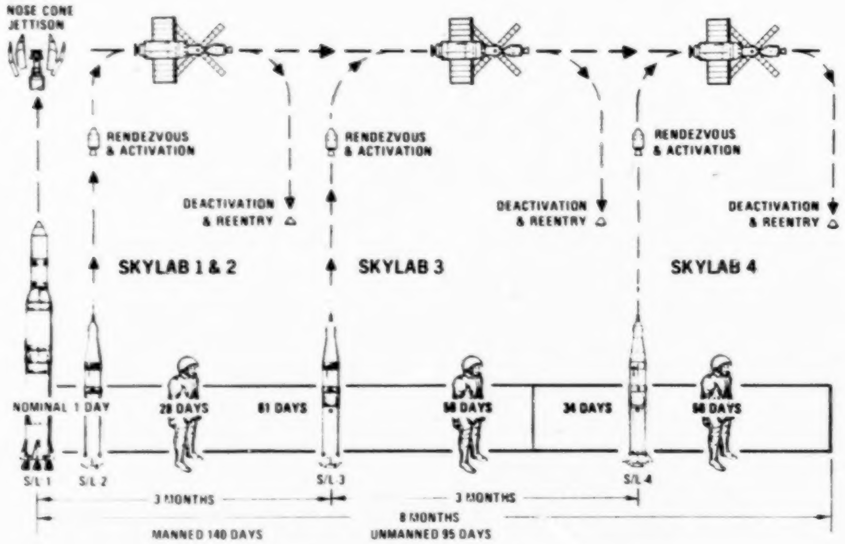

NOSE CONE JETTISON
RENDEZVOUS & ACTIVATION
RENDEZVOUS & ACTIVATION
RENDEZVOUS & ACTIVATION
DEACTIVATION & REENTRY
DEACTIVATION & REENTRY
DEACTIVATION & REENTRY
SKYLAB 1 & 2
SKYLAB 3
SKYLAB 4
NOMINAL
1 DAY
28 DAYS
61 DAYS
56 DAYS
34 DAYS
56 DAYS
S/L 1
S/L 2
S/L 3
S/L 4
3 MONTHS
3 MONTHS
8 MONTHS
MANNED 140 DAYS
UNMANNED 95 DAYS

Figure 14. Program mission profile.

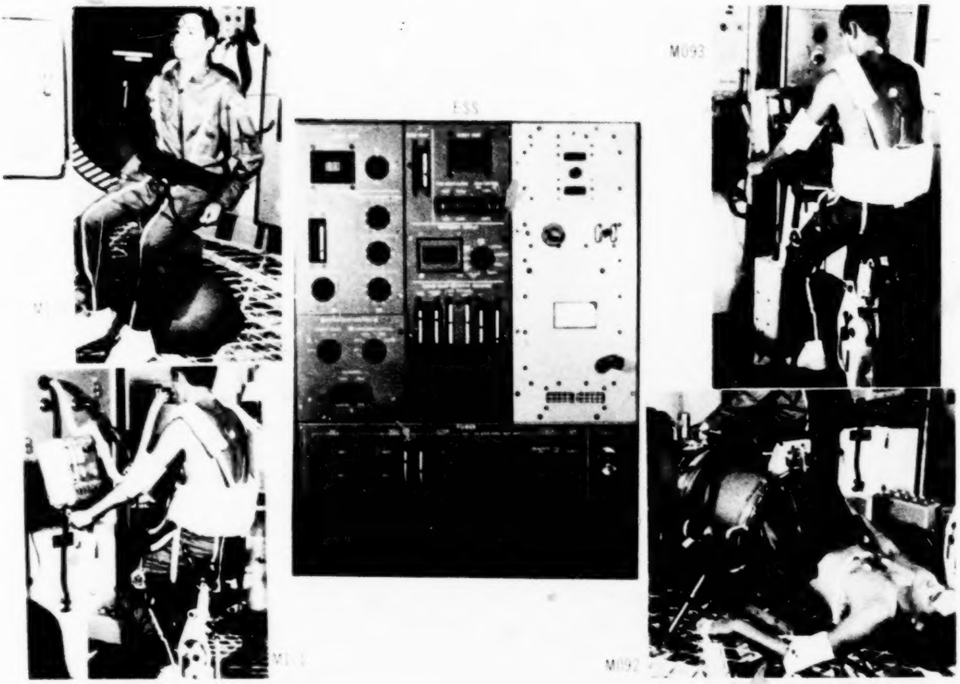

ESS
M093
M092

Figure 15. Experiment support system.

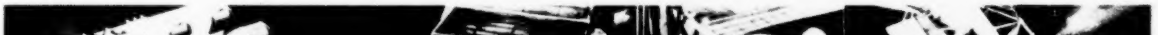

MULTISPECTRAL CAMERA
MULTIPLE DOCKING ADAPTER
IR SENSOR AND VIEWFINDER
CONTROL AND DISPLAY PANEL
MULTISPECTRAL SCANNER
RAD/SCAT AND ALTIMETER
RADIOMETER
TAPE RECORDER

Figure 16. Skylab - Earth Resources Experiment Package (EREP).

NOW THAT WE'VE CHECKED THE SNOW LEVEL AT ASPEN, LET'S GET A BIKINI COUNT AT MIAMI BEACH.
NASA

Figure 17. One of Skylab's many uses.

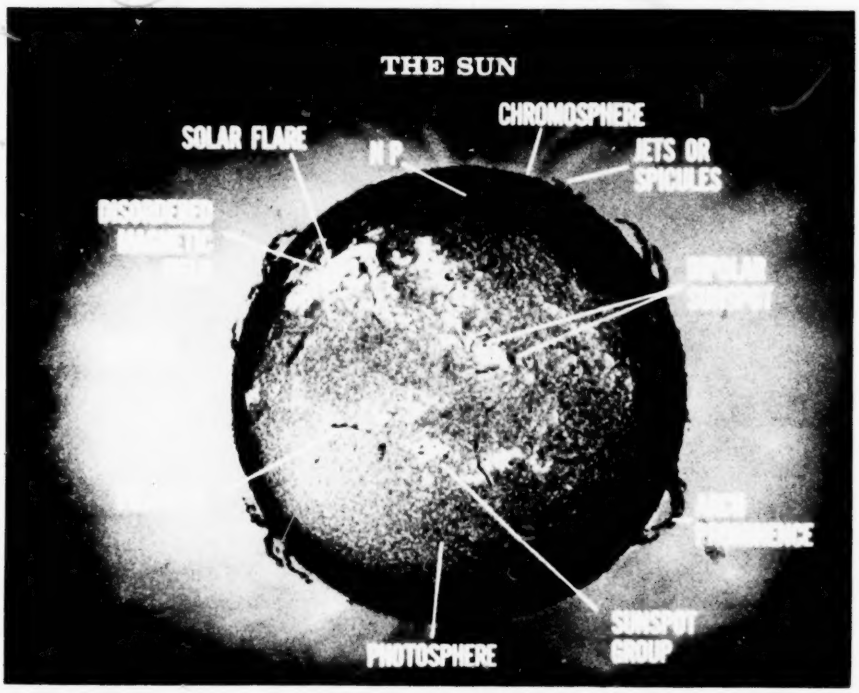

THE SUN
CHROMOSPHERE
SOLAR FLARE
N P
JETS OR SPICULES
DISORDERED MAGNETIC
BIPOLAR SUNSPOT
ARCH PROMINENCE
SUNSPOT GROUP
PHOTOSPHERE

Figure 18. Sun's surface.

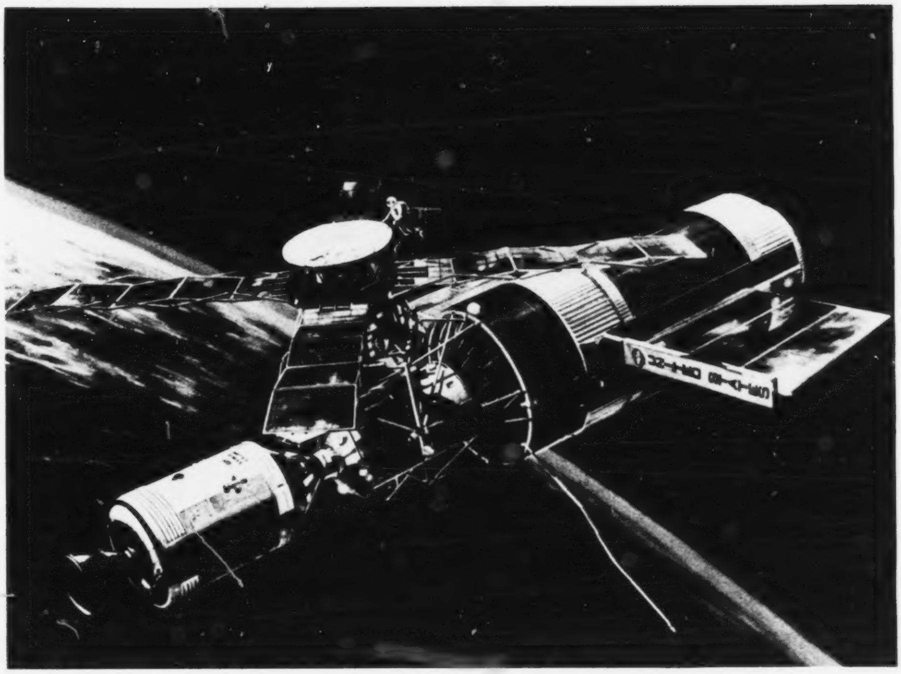
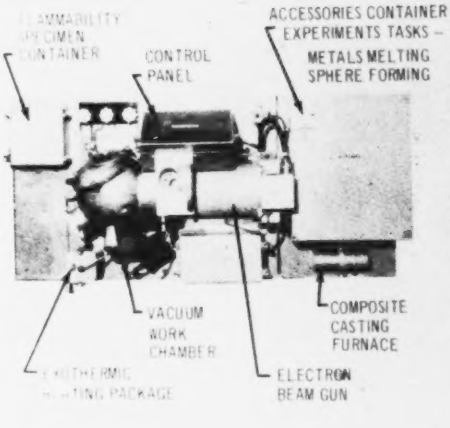


Figure 19. Film retrieval.


FLAMMABILITY SPECIMEN CONTAINER
CONTROL PANEL
ACCESSORIES CONTAINER EXPERIMENTS TASKS – METALS MELTING SPHERE FORMING
VACUUM WORK CHAMBER
COMPOSITE CASTING FURNACE
EXOTHERMIC HEATING PACKAGE
ELECTRON BEAM GUN

**PURPOSE**

EXPLORE SPACE MANUFACTURING APPLICATIONS OF MOLTEN PHENOMENA SUCH AS MOLTEN METAL FLOW, FREEZING PATTERNS, THERMAL STIRRING, FUSION ACROSS GAPS AND SURFACE TENSION.

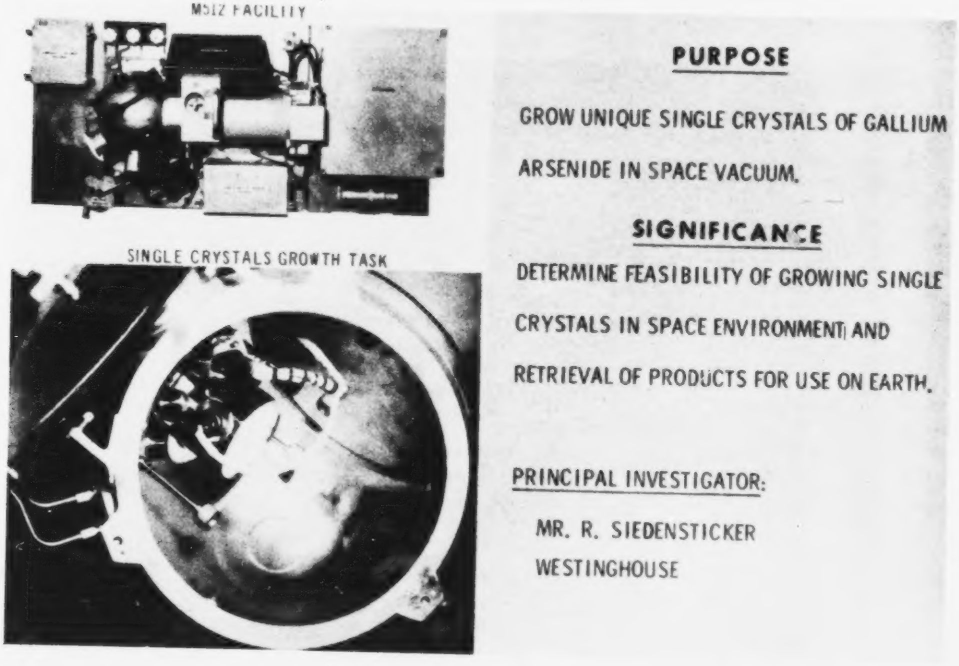
**SIGNIFICANCE**

CONSTRUCTION, ASSEMBLY AND REPAIR OF STRUCTURES OUTSIDE THE EARTH ENVIRONMENT AND RETRIEVAL OF VALUABLE PRODUCTS FOR USE ON EARTH.

PRINCIPAL INVESTIGATOR:

MR. P. GORDON PARKS,
MSFC

Figure 20. Materials processing in space facility (Skylab experiment M512).


M512 FACILITY
SINGLE CRYSTALS GROWTH TASK

**PURPOSE**

GROW UNIQUE SINGLE CRYSTALS OF GALLIUM ARSENIDE IN SPACE VACUUM.

**SIGNIFICANCE**

DETERMINE FEASIBILITY OF GROWING SINGLE CRYSTALS IN SPACE ENVIRONMENT AND RETRIEVAL OF PRODUCTS FOR USE ON EARTH.

PRINCIPAL INVESTIGATOR:

MR. R. SIEDENSTICKER
WESTINGHOUSE

Figure 21. Materials processing in space - single crystals growth task (Skylab experiment M512).

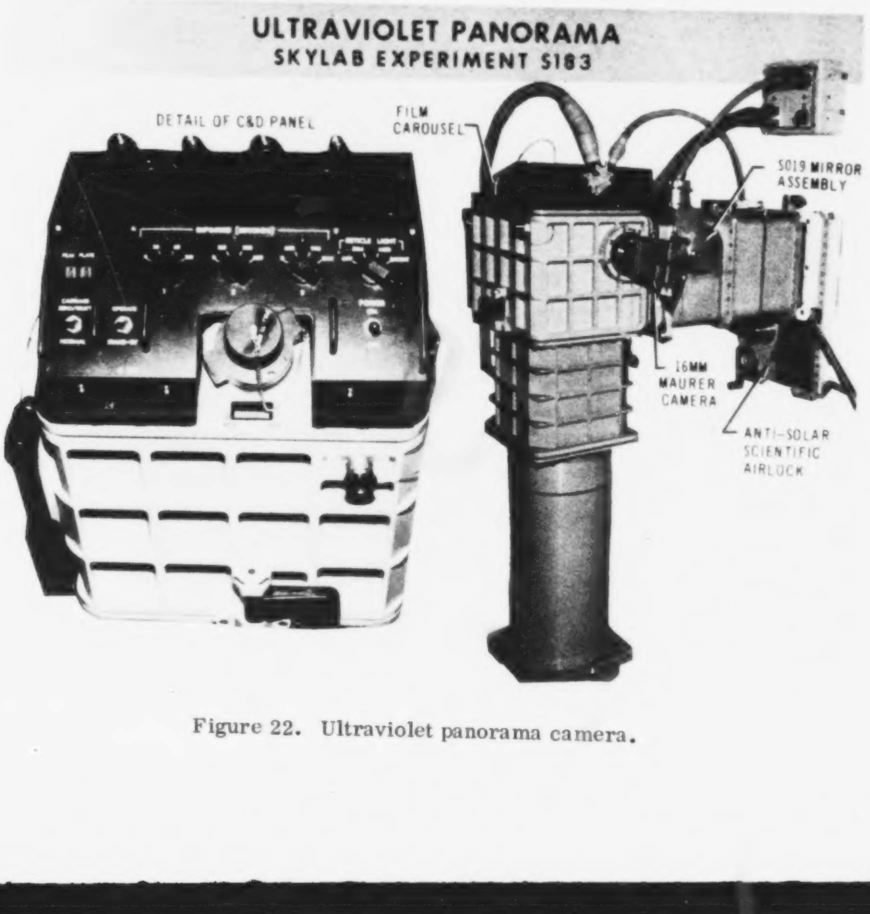

ULTRAVIOLET PANORAMA
SKYLAB EXPERIMENT S183
DETAIL OF C&D PANEL
FILM CAROUSEL
S019 MIRROR ASSEMBLY
16MM MAURER CAMERA
ANTI-SOLAR SCIENTIFIC AIRLOCK

Figure 22. Ultraviolet panorama camera.

## PROGRAM OBJECTIVE

STIMULATE INTEREST IN SCIENCE AND TECHNOLOGY BY DIRECTLY INVOLVING STUDENTS IN SPACE RESEARCH

Figure 23. Program objectives.

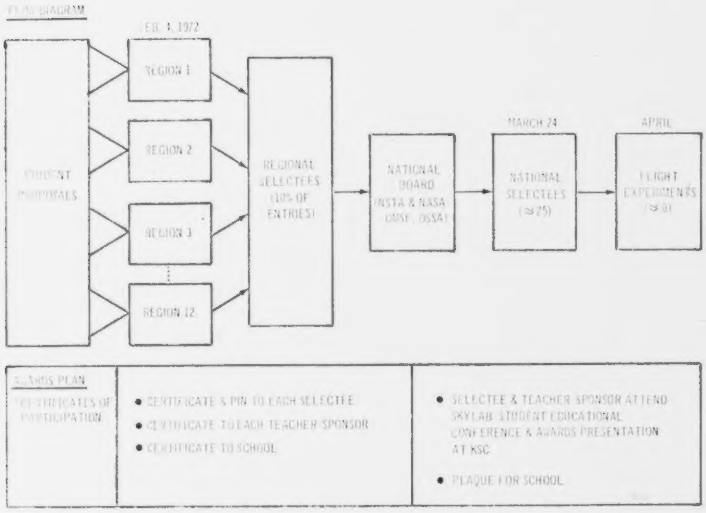

FLOW DIAGRAM
FEB. 4, 1972
STUDENT PROPOSALS
REGION 1
REGION 2
REGION 3
REGION 12
REGIONAL SELECTEES (10% OF ENTRIES)
NATIONAL BOARD (NSTA & NASA OMSF, OSSA)
MARCH 24
NATIONAL SELECTEES (≈25)
APRIL
FLIGHT EXPERIMENTS (≈6)
AWARDS PLAN
CERTIFICATES OF PARTICIPATION
• CERTIFICATE & PIN TO EACH SELECTEE
• CERTIFICATE TO EACH TEACHER SPONSOR
• CERTIFICATE TO SCHOOL
• SELECTEE & TEACHER SPONSOR ATTEND SKYLAB STUDENT EDUCATIONAL CONFERENCE & AWARDS PRESENTATION AT KSC
• PLAQUE FOR SCHOOL

Figure 24. Skylab student program sequence of major events.

(Approved by Administrator)

- SIX EXPERIMENTS
  - TOTAL LAUNCH STOWAGE SPACE 1 CUBIC FOOT
  - TOTAL WEIGHT 35 LBS
  - TOTAL CREW TIME 1-1/2 MAN-HOURS PER WEEK
- CRITERIA FOR EXPERIMENT EQUIPMENT ESTABLISHED
  - COMPATIBILITY
  - PROGRAM IMPACT
- COST ESTABLISHED
  - SELECTION PHASE - 65K
  - DEVELOPMENT & INTEGRATION - 200K

Figure 25. Major features.

HOW LONG DO I HAVE TO WAIT FOR MY WATER?
POLLUTED AGAIN!!!
I'M GLAD SOMEONE IS SEARCHING FOR A POLLUTION SOLUTION

Figure 26. One of Skylab's benefits.

# THE POTENTIAL IMPACT OF THE SPACE SHUTTLE ON SPACE BENEFITS TO MANKIND

By Ivan Rattinger
Department Program Manager, Space Shuttle Division
Convair Aerospace Division
General Dynamics Corporation

## Introduction

The Space Age may be divided into three general decades:

- The sixties, during which the initial steps of space exploration were undertaken.
- The seventies, when it can be anticipated that the successful explorations of the preceding decade will be developed into practical applications.
- The eighties, when developed capabilities will be put to extensive use.

The benefits to mankind are beginning to appear in ever-increasing amounts (Fig. 1):

- During the sixties, these benefits generally took the form of space technology applied to uses on earth; e.g., materials, electronic components, computers.
- During the current decade, these benefits will increase to include systems operating from space; e.g., weather prediction, communications.
- During the next decade, these benefits will further increase because of new applications (e.g., earth resources and navigation) and the ability to conduct more space operations (for a fixed budget) through the reduced costs of both transportation and payloads arising from development of the Space Shuttle.

This discussion will concentrate on Shuttle-induced benefits.

Near-Earth Space. Space can be conveniently divided into three areas (Fig. 2):

1. Escape, which includes the lunar and planetary areas; that area beyond the influence of the earth's gravitational field.

2. Synchronous is that altitude at which a satellite will remain above a fixed point on the earth.

3. Near-earth is a region below the inner Van Allen belt (~ 500 n. mi.). This area is generally further limited to about 80 to 270 n. mi., the former established by premature orbit decay, the latter by excessive performance requirements.

Typical payload types and their relative status are also shown for each space area.

Near-earth missions are directly supported by the Shuttle. Operational areas for both the Space Shuttle and Tug are noted on the accompanying chart. Synchronous and escape missions require both a Shuttle and a Tug: the former to place the Tug and payload in near-earth orbit, the latter to transfer the payload to the final orbit.

Space Mission Characteristics. Figure 3 indicates the weight of payloads placed in near-earth (80 to 270 n. mi.) orbit and into synchronous and escape orbits. For the latter payloads, an appropriate stage (Tug) is required for transfer from near-earth orbit to the final payload destination. Typical weights for this stage are also shown. When stage weight is added to that of the payload, an equivalent weight to near-earth orbit can be determined. These results are noted in the last graph and form the basis for the Space Shuttle payload requirements. The difference in Shuttle performance required for the two missions is accommodated by the variation in the launch azimuth required to support each mission. Synchronous and escape missions are generally launched in an easterly direction and are thereby aided by the earth's rotation.

Thus, a Shuttle with the ability to launch 40 000-lb payloads, in support of near-earth missions, and 65 000-lb payloads, in support of synchronous/escape missions, will have the capability to capture the forecast average of 30 near-earth and 20 synchronous/escape missions per year.

Current United States Space Launch Systems Inventory. The current U.S. inventory of space launch systems accommodates a wide range of payload weights to near-earth orbit, increasing (Fig. 4, from left to right) from about 300 lb for the Scout to about 250 000 lb for the Saturn V. With the continuing reduction in the number of payloads launched each year, maintaining this extensive inventory is becoming increasingly inefficient.

Future Space Launch System Inventory. Development of the Space Shuttle in accordance with the capabilities previously described would allow the U.S. space launch system inventory to consist of only the Scout vehicle and the Shuttle (Fig. 5). This inventory retains the capabilities of the current space launch system fleet and, in addition, affords the following desirable characteristics:

- Economic for both low and high launch rates
- New modes of operation, resulting in the potential for significant payload cost reductions
- A high degree of standardization, leading to reduced costs for payload integration, flight operations, and personnel support.

## Mission Profile

Significant elements of the Space Shuttle mission profile are ground operations, launch, and staging of the two Shuttle vehicles (Fig. 6).

After staging, the first stage (booster) returns to the launch area, while the second stage (orbiter) attains the prescribed insertion orbit after a series of orbital maneuvers. The orbiter then delivers and/or retrieves its payload, enters the atmosphere, acquires the landing site, and completes the approach and landing.

Safing operations are completed on each stage at the landing area, preparatory to the turnaround cycle ground operations. After payload installation in the orbiter, the orbiter is mated with the booster, and the mated system is made operationally ready and transported to the launch area for a new mission.

This sequence of events is described in more detail in the following pages, starting with servicing the vehicle in the Maintenance and Refurbishment (M&R) facility.

Space Shuttle Vehicles in M&R Facility. The booster and orbiter are shown in Figure 7 during maintenance operations within the M&R facility, which provides a protected environment for performing turnaround maintenance, premating, and erection tasks. M&R includes the area for mating and erecting the vehicles. Scheduled (time- or event-oriented) maintenance will be minimized, and airline-type condition monitoring techniques will be maximized to provide the rapid, reliable turnaround cycle required by the Space Shuttle program.

Erection, Checkout, and Preflight Handling Sequence. Upon completion of turnaround maintenance activities in the M& R area, the booster and orbiter are ready for mating activities and subsequent prelaunch activities. These activities account for approximately 70 percent of the ground turnaround elapsed time. Of this period, erecting, mating, transporting, and connection to the launch pad require approximately 80 percent of the time. Establishment of a minimum time interval of the vehicle on the launch pad is governed by:

- Rescue contingencies
- Accomplishment of the high rate of operational launches with existing facilities.

The vehicle and support equipment design (plus the planned sequence of operations) will contribute to the achievement of a minimum on-stand time for the vehicle.

Vehicle Erection and Mating in the High Bay. Erection and mating operations are accomplished in the existing high-bay area of the Vertical Assembly Building:

- The booster is hoisted first, and installed on the mobile launcher with the upper surface of the booster facing away from the launcher umbilical tower.

- The orbiter is then hoisted and placed on the upper surface of the booster.

This orientation and sequence of operations will allow booster erection in advance of the orbiter and provide better clearance for the mating operation. These aspects promote flexible scheduling and rapid mating operations.

Vehicle Transport to Launch Pad. The Space Shuttle is mated on the mobile launcher, and moved to the launch pad on the existing crawler-transporter. The crawler-transporter engages the mobile launcher in the Vertical Assembly Building, moves the launcher to the launch pad, and then disengages from the launcher. The transport task will require approximately 10 hours.

This transportation method was selected after studying various other horizontal and vertical techniques. The selected method allows use of existing equipment that will support the turnaround requirements and significantly reduce program cost.

Terminal Countdown. As currently planned, the terminal countdown is a brief evaluation of the active functional paths required for the mission. The prime control will be onboard, with ground personnel providing expertise as may be required. A minimum number of monitor consoles and positions will be used. These measures reflect a marked contrast to the large numbers of support personnel and long countdown times required for present manned launch vehicles.

Board Personnel. It will be possible to enjoy great freedom of movement in the "shirtsleeve" environment of the passenger/crew compartment. In this environment, bulky spacesuit equipment, with its complex connections, is eliminated. Because the crew is not encumbered by this equipment, a rapid boarding (or deboarding) process is possible with simplified closeup tasks.

Mated Shuttle Vehicle at Liftoff. The Shuttle vehicle, with main engines ignited, is shown at about the time of liftoff from the pad in Figure 8. After liftoff, the vehicle will rise vertically to a point approximately 100 ft above the launcher umbilical tower. At this point, first the roll then pitch programs will be initiated to achieve the desired trajectory. The guidance system will be an autonomous onboard system.

Mated Shuttle Vehicle During Boost. Loads induced during mated flight will be reduced through the use of a load-relief flight control program. Under normal conditions, flight crew tasks are of a monitoring nature during this phase of flight. The mated Shuttle vehicle follows a preprogrammed flight path. Safe abort and landing are possible, if required, during this phase of the flight.

Space Shuttle at Staging. The booster and the orbiter are shown in Figure 9 at staging, with the orbiter continuing on its mission and the booster preparing to descend. The separation sequence is initiated by appropriate sensors monitoring booster propellant levels. To separate the vehicles, combined booster and orbiter thrust is employed through a mechanical leverage system.

The orbiter will continue, under thrust, to its defined orbit, while the booster will initiate a turning descent for return to the launch base (Fig. 10). The booster will enter the atmosphere in an entry mode that will attain a maximum of 4 g for a short time.

This concept of separation was selected after a study of several methods, because it provides excellent separation characteristics at normal staging, as well as rapid separation any time during mated flight.

Booster During Cruiseback to Launch Site. Following separation from the orbiter and atmospheric entry, the booster uses its airbreathing engines to cruise back to the launch site at an altitude of approximately 10 000 ft (Fig. 11). Federal Aviation Administration (FAA) contact and control are anticipated for the flyback operation. Takeoff and cruise capability also enables the booster to make normal cross-country ferry flights.

Booster at Landing. The booster will return to the runway at the launch site approximately 2 hours after launch (Fig. 12). Landing is similar to that of a conventional jet aircraft. After landing rollout, the booster will taxi to the safing area. Selection of the launch site as the primary return site for the booster permits sharing facilities.

Should an alternative landing site be required because of an abort or to maximize performance capability, any conventional 10 000-ft runway, with standard landing aids, will serve as a landing site.

Booster in the Safing Area. After taxi from the runway area, the booster will be made safe for subsequent operations (Fig. 13). Any residual main engine, power system, or attitude control propulsion system propellants and resulting evaporated gases will be drained and purged to an inert level so that turnaround maintenance can be accomplished in a nonrestricted, nonexplosive environment in the maintenance building.

Orbiter Unloading Payload at Space Station. During this mission phase, the orbiter is the active element in transferring the payload. Orbit maneuvering is provided by the orbiter maneuvering system. The orbiter cargo-handling and stabilization control will be easily accomplished. After the Space Station/orbiter combination is configured and stabilized, cooperative procedures will be implemented for cargo transfer activities (Fig. 14).

Orbiter During Entry. Orbiter entry (Fig. 15) will be accomplished at a velocity significantly higher than that of the booster, thereby requiring a thermal protection system that will survive extreme entry heating. Entry will normally be accomplished in the vicinity of the landing site which, for nominal conditions, will be the launch site.

The orbiter thermal protection system is designed to provide the capability for 1100 n. mi. of aerodynamic crossrange.

Orbiter at Landing. Landing characteristics of the orbiter are comparable to current high-performance aircraft (Fig. 16). Unlike the booster, the orbiter is capable of landing either with or without airbreathing engines. Consequently, use of airbreathing engines will be dictated by mission requirements that, in turn, will depend upon payload weight, landing site, ferry requirements, etc.

Upon completion of the landing phase, the orbiter undergoes a safing procedure similar to that conducted upon the booster vehicle.

## Capabilities

Apportionment of stage sizes to the two-stage launch vehicles (Fig. 17) permits satisfaction of a variety of missions in the most cost-effective manner.

The ability to transport or retrieve a variety of orbital payloads affords the flexibility to support all anticipated space applications with the same basic launch vehicle (Fig. 18).

The ability to provide service to payloads and/or personnel on orbit extends the previously noted capability to the space environment (Fig. 19). Space rescue is one such extended capability; another is economical Space Shuttle Station logistic resupply.

System reusability (Fig. 20) affords both low recurring transportation costs and the ability to amortize Shuttle development costs within the operational life of the program. Additional capabilities include:

- Development of earth-oriented equipment through sortie mode flights
- Reduction in losses due to abort or satellite failure
- On-orbit scientist participation.

## Cost Effectiveness

Reducing the Cost of Space Operations. The Space Shuttle has a design goal of reducing by an order of magnitude the cost of transporting payloads, both manned and unmanned, to low earth orbit. Even greater reductions are possible in placing satellites into synchronous and other high-energy orbits. These goals can be achieved with the Shuttle vehicle currently defined (Fig. 21).

Additional savings are also possible because of the manner in which the Shuttle operates. The intact abort capability (separate and safe recovery of both orbiter and booster after malfunction), for example, provided by the Shuttle will further reduce the cost of payload losses because of launch vehicle failures will no longer be experienced. Also, the ability to return payloads should reduce "infant mortality" losses to essentially the cost of a second Shuttle launch. Payload design may take further advantage of this ability to allow periodic refurbishment or upgrading of failed or obsolescent payloads.

The value of diagnostic study of prematurely failed space payloads should not only prevent recurrence of such failures, but should afford the payload designer a better understanding of operational margins of safety. Finally, the ability to guarantee placement of time-critical payloads has a significant but difficult to quantify value.

The benign environment of the Shuttle cargo bay (e.g., low g-loads, an absence of shock loads induced by pyrotechnics, and the ability to continuously support the payload along its length) will result in substantial reductions in the cost of payload design, development, qualification, and production. Such features, coupled with relaxed payload weight and volume restrictions (for all but the most demanding payloads), should make it possible to design payloads in a more economic manner.

The ability to perform experiments in space in an economic manner is yet another Shuttle-derived benefit. To date, many desirable experiments have been defined, but their implementation has been impeded by the high cost of transporting the payload to orbit, the cost of man-rating the launch vehicle for manned payloads, or the cost of fabricating the payload itself. In each area, the Shuttle offers significant benefits. It requires no additional man-rating, since the orbiter element of the Shuttle may be used as the experiment base for periods up to 30 days. Thus, the need to develop a specific payload vehicle can, in many cases, be restricted to the development of experiment-peculiar instrumentation. Indeed, because of the Shuttle environment and the availability, if desired, of supporting technicians on orbit, many space experiments may be conducted with laboratory-quality equipment rather than the more costly space-qualified equipment.

Space Shuttle: Fundamental to Future Space Development Activities - I. As currently conceived, the Shuttle is the keystone to future space development activities. In addition to the payload implications previously noted, the Space Station (Fig. 22), Space Tug (Fig. 23), and Research & Applications Modules (RAM) (Fig. 24) depend upon the Shuttle for transport to orbit, support while in orbit, and, when appropriate, return to earth. The ability to incorporate these programs, in an orderly development, depends on the Space Shuttle.

In view of the sequential dependency of the other advanced space program elements, the Shuttle is, in effect, the only viable early program start. Indeed, much of current space program planning is predicated upon early development of the Space Shuttle; e.g., future Space Stations are based on extended orbital stay times for both technical and economic reasons and such stay times are practical only with economic logistic resupply.

Space Shuttle: Fundamental to Future Space Development Activities - II. From the frame of reference of the Space Shuttle, there need be no dependent commitment to develop any of these other systems; however, their development could be a natural follow-on to the basic Shuttle program. Accordingly, it is at the discretion of the President and Congress when and if these activities are initiated. But the ability to incorporate them into an orderly development is available so long as the Shuttle vehicle is present.

## Impact Upon Technological Superiority

Current Space Program. Principal features of the current space program (Fig. 25) are, briefly:

1. A reduction in funding from the peak achieved in the late sixties

2. An accelerating-reduction in employment featuring:

   a. Declining numbers of scientists/engineers employed

   b. Those who leave do not wish to return

   c. Rapid "aging" of engineers and scientists employed in the aerospace industry

   d. Declining numbers of engineers and scientists enrolled in universities

   e. Disenchantment of young people with technology and aerospace.

3. Reduction in the annual launch rate and pounds of payload placed in orbit from the peak achieved in the late sixties

4. Essentially, completion of technological advances arising from the current space program. (Note, this does not mean completion of such advances to new products and/or the "reduction to practice" of such advances.)

Without a reversal of these trends, the U.S. may be compromising its ability to meet future national goals.

National Goals. A persuasive argument can be made that an early Space Shuttle contract go-ahead is a reasonable and prudent step that would contribute significantly to attainment of those national goals that almost everyone considers to be fundamental to a healthy and vigorous national posture.

As a democratic and dynamic society, we in the U.S. have many and changing national goals. Although there is wide disagreement as to relative priorities among the various national goals, almost everyone will agree that three are very high on any rational priority list (Fig. 26):

1. Maintenance of National Security — Our national security forces must have two basic characteristics:

    a. Quality essentially equal to, or superior to, the forces being countered.

    b. Timely deployment consistent with the attainment of substantial operational capability by the forces being countered. (Too little [in quality] or too late [in deployment] is not acceptable. Maintenance of national security is contingent upon the ability [not necessarily the act] to deploy quickly quality weapon systems which, in turn, requires maintenance of a superior technological capability.)

2. Improvement of Economic Vitality — In a highly industrialized society, such as ours, the creation of new job opportunities is heavily dependent on the application of the fruits of a continuously expanding technological base to develop new products. Expanding technological capability is thus a prerequisite to the creation of the job opportunities that are essential to maintaining and improving economic security. If the nation is to improve its economic vitality, it must maintain a favorable balance of trade in the face of increasing competition from nations with rapidly expanding industrial and technological capabilities. Over the long term, this can be achieved only if technological superiority is maintained.

3. Enhancement of the "Quality of Life."

Enhancement of the "Quality of Life." If we are secure, and if our economy operates efficiently, the diversity of technological innovations that flow from maintenance of technological superiority will regularly continue to enhance our quality of life. In advancing the quality of life, our nation must cope with many problems, among them:

1. Providing opportunities for all citizens to obtain:

    a. Education consistent with their abilities

    b. Gainful employment

    c. Security from poverty

    d. High-quality medical care

    e. Recreational and cultural opportunities.

2. Reduction in crime

3. Control of environmental pollution

4. Relief from the congestion and frustrations that plague both our urban communities and our urban commuters (Fig. 26).

Expanding technological capability does not, in itself, ensure that these critical problems will be resolved. These problems can be resolved only by a combination of a national commitment to resolve them, coupled with the technological innovations required to resolve them, which can flow only from an expanding technological capability.

Requirement for Technological Superiority. It seems plain that nourishment of our technological base to ensure an expanding technological capability is essential to the achievement of such high-priority national goals as national security, improved economic vitality, and enhancement of our quality of life (Fig. 27). It follows, therefore, that commitment of resources to programs that focus around the sustenance and enrichment of our technological base is not, as some argue, "Counter-productive to the new ranking of national priorities," but rather is mandatory if the desired national goals are to be attained. Thus, the maintenance of technological superiority should have high national priority, regardless of the current reevaluation of the rankings of natural goals. Technological superiority is a vital prerequisite to the attainment of almost all national goals.

Elements of Technical Superiority. Technical superiority is achievable through the complex and interrelated working of four categories of activities (Fig. 27):

1. Conducting exploratory research in the interest of advancing technical superiority

2. Developing and "reducing to practice" state-of-the-art technology

3. Improving and extending present technical skills

4. Sharpening and refurbishing applied technical tools.

The end products of the beneficial coordination of these activities are the hardware, processess, tools, and skills that comprise "Technical Superiority."

Maintenance of Technological Superiority. Maintaining technological superiority depends upon the continuing health of five distinct but related areas (Fig. 28):

1. Basic research across a broad front

2. Applied research in selected areas

3. "New blood" in the form of young scientists and engineers

4. Major, technically challenging development programs of national scope

5. Multidisciplinary management/scientific/engineering/production teams that integrate and motivate government, university, and industrial organizations.

Justifications for the first two areas will not be repeated here, since they are familiar and not directly related to a case for Space Shuttle. The latter three items are relevant and will be treated in some detail in the following pages.

Availability of Engineers and Scientists for Future "Cutting Edge" Development Programs. One of the five elements essential to maintaining technological superiority is the ability to continually attract "new blood" — young scientists and engineers — to the development programs that form the "cutting edge." In the current environment, both opportunities for the attractions for young scientists and engineers to join active advanced development teams have vanished. As teams undergo forced reductions, a disproportionately high percentage of young engineers and scientists are among those laid off.

This combination of essentially a zero inflow and a disproportionately high outflow of young engineers and scientists has resulted in the unfavorable trend that the average age of engineers and scientists employed in the aerospace industry is increasing by more than 1 year per calendar year.

The lack of opportunity, coupled with the disenchantment of young people with technology and, in particular, with the aerospace industry, has resulted in another unfavorable trend: reduction in science and engineering and enrollment in our colleges and universities, even as total enrollment continues to increase. Enrollment of full-time students in engineering schools, for instance, decreased by 9500 during 1969 and 1970, and master's degree candidates have decreased by 18 percent since 1968. All signs indicate that the production of scientists and engineers in the Soviet Union is continuing to increase.

A large proportion of scientists and engineers who have left the aerospace field has been irreversibly lost. It has been our experience that the majority of such engineers will not consider rehire (even if offered large salary increases), because they seek more certain futures in stable fields that are free of political reevaluation. There is a sense of anxiety about working in a career area that is strongly impacted by public whim or by a new-found popular disfavor with technology.

Aerospace industry engineering and scientific employment has declined from a peak of 223 000 in 1963, to a current level of 175 000, and the slope is still depressingly steep downward. The projections indicate that this trend will continue, although, at a slower rate, even if new national programs are initiated in the immediate future.

The human resources that should be available to future integrated and multidisciplinary development teams are in jeopardy due to the five factors discussed briefly above (Fig. 29):

1. Declining number of engineers and scientists employed in the aerospace industry

2. Surprisingly strong determination of those who have left, never to return

3. Rapid "aging" of engineers and scientists employed in the aerospace industry

4. Declining enrollment of science and engineering students

5. Disenchnatment of young people with technology — particularly with the aerospace industry.

As a result, the nation may lack the human resources required to maintain our technological level in the seventies, and may find itself irreparably behind the power curve in the decade of the eighties. Implementation of a single major program development will not, by itself, correct this bleak situation, but inauguration of the Shuttle will be a step in the right direction.

Major Programs as the "Cutting Edge" of Technological Advancement. New programs that serve as the foci that forge the "cutting edge" are now urgently required to replace the Intercontinental Ballistic Missile (ICBM) and the Apollo programs. It will not be as easy to rally congressional and public support for new programs in the current environment. The direct goals of a program, such as Space Shuttle, will not be as apparent or considered as critical as were those of the ICBM or Apollo. The indirect benefits — serving as the "cutting edge," which are equally important, indeed, critical to the maintenance of national technological capability — are not generally appreciated or well understood by the American public. Although the difficulties in advocating such programs are today more severe, the critical necessity for such "cutting edge" programs that permit the momentum of technological advance to continue is no less real.

It is essential that Congress and the public be afforded a better understanding of three aspects of technology (Fig. 30):

1. The role of technology as the progenitor of major programs

2. The long lead times required to reach the technical "payoff"

3. The difficulties involved in distributing the resources required to balance the technical effort.

Integrating Influence of "Cutting Edge" Programs. Characteristically, our nation has had a high degree of success in bringing together the knowledge (gathered from basic research and applied research) and the people (scientific, engineering, and technical personnel organized in multidisciplinary teams) to improve our technical and economic capability; these resources have been applied in a major program toward the end of obtaining a new, better, or less expensive product. But important byproducts of these efforts have been:

1. Stimulation of new concepts

2. Advances made in technology — the state of the art

3. Translation of scientific information into engineering and technical skills

4. Sharpening and refurbishing operating tools, skills, and processes (Fig. 31).

Major "Cutting Edge" Programs. In our generation, the U.S. has made a dramatic advance in its technological capability. The momentum of this advance has depended upon the "cutting edge" provided by major national programs that focused advanced management, scientific, engineering, and production talents on achieving specific capabilities at specified times (Fig. 32).

In World War II, for example, high-performance aircraft, radar, the atomic bomb, and other specific weapon systems served as the foci and provided the catalyst for a surge in technological capabilities. These programs were readily supported by Congress and the American public, not because they advanced technological capabilities, but because they were considered essential to prosecuting the war effort and, therefore, essential to national survival.

In the cold war period, the hydrogen bomb, ICBM, and nuclear submarine programs served as similar foci and forged the "cutting edge" of continuing growth in technological capability. These programs were also readily supported by Congress and the American people. Again, not because they forged the cutting edge, but because they were considered essential to national defense.

Later, the response to Sputnik, culminating in the Apollo program, increased our awareness of the need to sharpen the "cutting edge" and ensured the momentum that maintained our technological superiority. This effort was also readily supported by the Congress and the American public as a result of the shock of Sputnik and the call of President Kennedy to a great adventure: "to be the first people to walk on the moon."

Thus, during our generation, major cutting-edge programs have found support — but this massive support has been forthcoming for reasons other than the assurance of national technological leadership.

Required Program Features. The required program features enumerated in Figure 33 serve as a checklist to test the suitability of candidate programs. Briefly, these features are:

1. Technology advance to support "technical superiority" through the interrelated working of the four noted activities

2. Capability of a near-term program start

3. Maintenance of and, perhaps, modest increase in engineering work force

4. Ability to achieve a reasonable rate of return through implementation of a major program that can serve as the "cutting edge" that permits the momentum of technological advance to continue

5. Ability, if desired, to expand to other programs in a controlled and predefinable manner

6. Ability, if desired, to stretch program development in an efficient manner to conform to currently unforeseen funding limitations

7. Ability to include international participation in an orderly and mutually satisfactory manner.

Required Results of New "Cutting Edge" Programs. "Cutting edge" programs must be of a magnitude (in terms of resources committed), urgency, and level of technical difficulty that the Nation will recognize the critical contribution that the program will make and will be steadfast in giving the program its support. The salient requirements of such a program are noted in Figure 34.

Space Shuttle: Impact on National Technical Superiority. Space Shuttle can and should serve as the keystone of our future national space program. This belief is based on Shuttle's ability to serve as the keystone for future space development activities.

The Space Shuttle program is well suited to replace Apollo as the sharp "cutting edge" required to maintain national technological superiority. It will serve as a focus of and catalyst for advanced technology efforts in a variety of fields that have tremendous economic potential; e.g., high-temperature materials, lightweight structures, automatic checkout for complex systems, and hypersonic aerodynamics.

In addition, operational capabilities of the developed system will: (1) greatly increase our flexibility to perform space operations, (2) increase our opportunities to apply space systems to the direct benefit of man, and (3) greatly improve the economics of space operations.

In summary, the Space Shuttle program is ready to enter the development phase, will result in operational capabilities of great direct benefit to the nation, and, more important, can serve as the "cutting edge" of expanding technological capability. Without a near-term start of a major program, such as the Space Shuttle, the "cutting edge" that was keen during the Apollo development program will continue to grow dull, and soon, with a deceleration of technological advance, the Nation will lose its technological superiority.

## Impact Upon National Economics

Comparative Impact of Three Environment Programs. A Space Shuttle program will generate a higher level of indirect purchases (and therefore total purchases) than would an equivalent outlay for consumer spending, and a significantly higher level of indirect purchases than would the same dollar outlay for a residential housing construction program (Fig. 36). The total direct purchases attributable to each of the three programs were aggregated into eight industry groups. Two significant points are conveyed by these data:

1. The impact of the Space Shuttle will pervade the total economy into each industry group.

2. The Space Shuttle is the only alternative considered that will stimulate the aerospace industry, where there, currently, is a very high level of unemployment among highly skilled workers, scientists, and engineers.

Thus, of the three programs compared, the greatest impact, from the standpoint of total production, would result from the Shuttle program.

It is interesting to note that high-technology industries are the areas primarily affected by the

Shuttle program, whereas relatively low-technology industries are primarily impacted by the other programs. From this, one can discern that solutions to the high unemployment problem found among highly trained engineers, scientists, and skilled technicians would most likely be found in the Shuttle program.

The Space Shuttle program would also tend to favorably impact the U.S. balance-of-trade problem, since the program would require fewer imports than would be required for residential housing construction or consumer spending. Perhaps of equal significance is the fact that since the Shuttle program would stimulate high technology industries, it would ipso facto provide a greater stimulus to high-technology exports. This is of vital importance since the U.S. depends on high-technology export to maintain a favorable balance of trade. It is also important to note that, based on each industry's ratio of exports to total 1970 production, the Shuttle program would induce three times more total exports than the other two programs.

National Economic Benefits of Space Shuttle Program. In summary, the Space Shuttle program would have a favorable impact upon the U.S. economy in the following ways (Fig. 37):

1. The approximately $ 9.5 billion cost to the U.S. Government would stimulate about $ 20 billion of domestic production.

2. Many jobs would be created: more than 400 000 man-years in the aerospace industry and more than 280 000 man-years in nonaerospace industries. The current unemployment problem in the aerospace industry would be partially alleviated.

3. The U.S. balance-of-trade picture would be improved. Space Shuttle would require fewer imports than would a residential housing construction program or increased consumer spending of comparable size. Also, based upon the historical ratios of exports to total domestic production, the Space Shuttle program would induce more total exports than the other programs examined. More important the Shuttle will simulate those high-technology industries that have been the most significant source of U.S. exports in recent years.

## Conclusion

The Space Shuttle program, as currently defined, will:

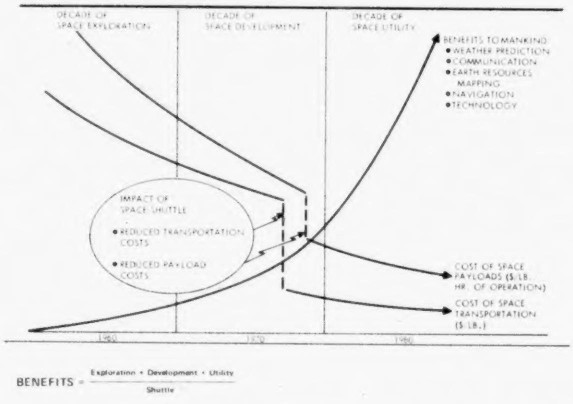
- Satisfy national space transportation requirements at reduced costs
- Permit additional savings to be made to payload development and operation costs

which, in turn, will

- Provide requisite "cutting edge" program for maintaining technical superiority
- Favorably impact national economy through increased employment. Production and balance of trade
- Expand practical space applications for mankind's benefit

and

- Support national goals.


DECADE OF
SPACE EXPLORATION
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SPACE DEVELOPMENT
DECADE OF
SPACE UTILITY
BENEFITS TO MANKIND
• WEATHER PREDICTION
• COMMUNICATION
• EARTH RESOURCES MAPPING
• NAVIGATION
• TECHNOLOGY
IMPACT OF SPACE SHUTTLE
• REDUCED TRANSPORTATION COSTS
• REDUCED PAYLOAD COSTS
COST OF SPACE PAYLOADS ($/LB. HR. OF OPERATION)
COST OF SPACE TRANSPORTATION ($/LB.)
1960
1970
1980
BENEFITS = Exploration + Development + Utility / Shuttle

Figure 1. Benefits from the Space Shuttle.

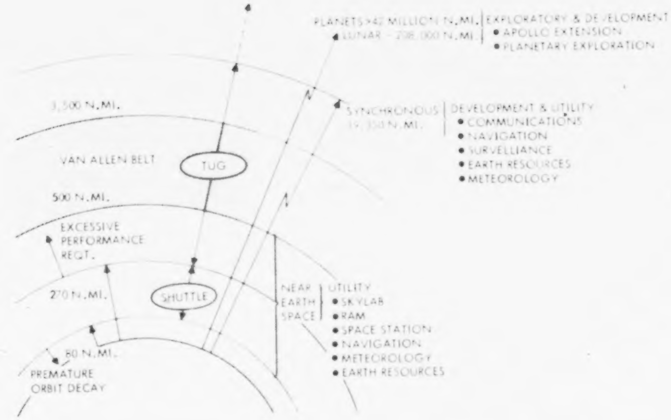

PLANETS >42 MILLION N.MI.
LUNAR - 208,000 N.MI.
EXPLORATORY & DEVELOPMENT
• APOLLO EXTENSION
• PLANETARY EXPLORATION
3,500 N.MI.
SYNCHRONOUS
19,350 N.MI.
DEVELOPMENT & UTILITY
• COMMUNICATIONS
• NAVIGATION
• SURVELLIANCE
• EARTH RESOURCES
• METEOROLOGY
VAN ALLEN BELT
TUG
500 N.MI.
EXCESSIVE
PERFORMANCE
REQT.
270 N.MI.
SHUTTLE
NEAR EARTH SPACE
UTILITY
• SKYLAB
• RAM
• SPACE STATION
• NAVIGATION
• METEOROLOGY
• EARTH RESOURCES
80 N.MI.
PREMATURE
ORBIT DECAY

Figure 2. Space regions and operations for the Space Shuttle and Space Tug.

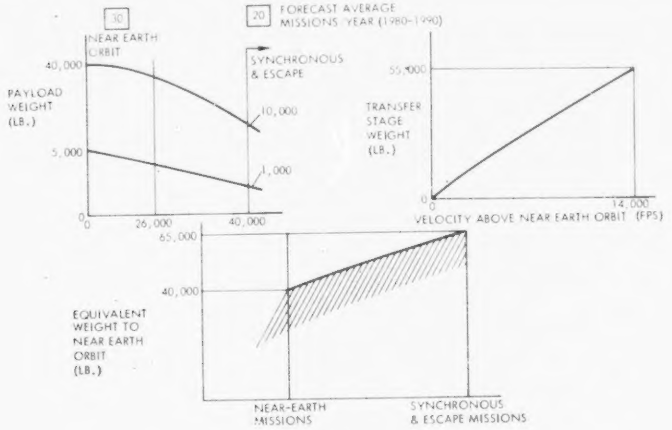
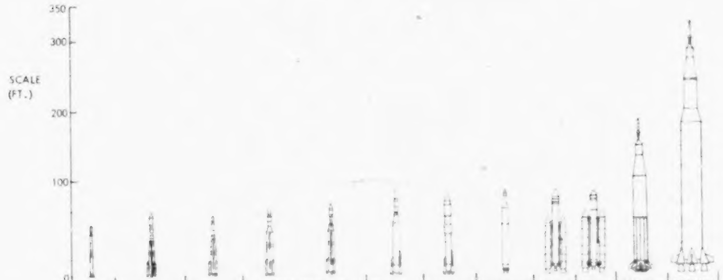


Figure 3. Weight of payloads at various orbits.


350
300
SCALE (FT.)
200
100
0

| | SCOUT | TAT-DELTA (IMPROVED) | THOR AGENA D | LONG TANK TAT AGENA D | LONG TANK TAT IMP. DELTA | ATLAS AGENA D | ATLAS CENTAUR | TITAN IIIB AGENA B | TITAN IIIC | TITAN IIID | SATURN IB | SATURN V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PAYLOAD WEIGHT TO NEAR-EARTH ORBIT (LB.) | 300 | 3,000 | 4,000 | 5,000 | 4,000 | 8,000 | 12,000 | 9,000 | 26,000 | 32,000 | 41,000 | 250,000 |
| COST PER LAUNCH ($M) | 3 | 6 | 8 | 8 | 6 | 9 | 11 | 9 | 15 | 11 | 50 | 200 |

Figure 4. Current U.S. inventory of space launch systems.

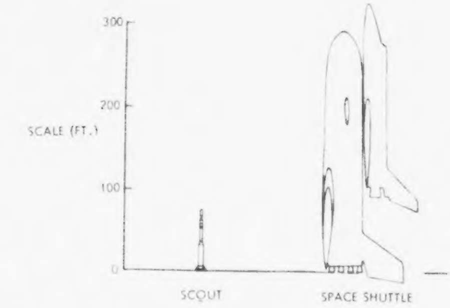

300
200
100
0
SCALE (FT.)
SCOUT
SPACE SHUTTLE

Figure 5. Comparison of the Scout and Space Shuttle.

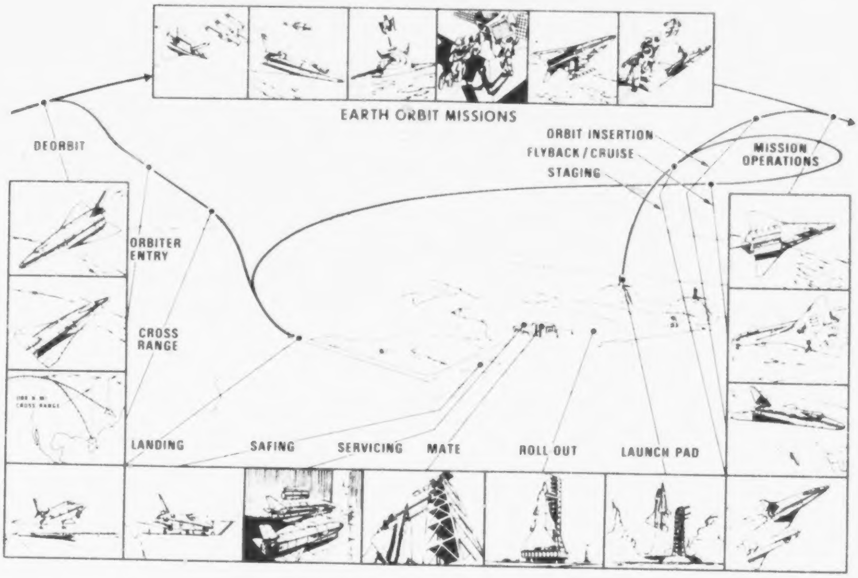

EARTH ORBIT MISSIONS
DEORBIT
ORBIT INSERTION
FLYBACK/CRUISE
STAGING
MISSION OPERATIONS
ORBITER ENTRY
CROSS RANGE
LANDING
SAFING
SERVICING
MATE
ROLL OUT
LAUNCH PAD

Figure 6. Mission profile.

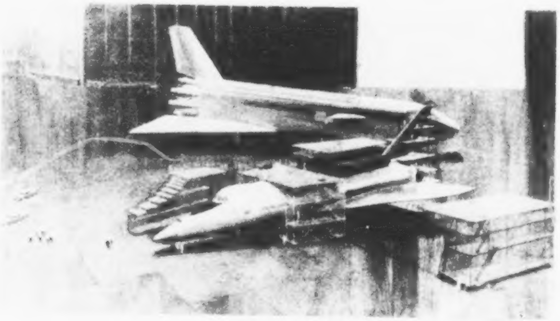


Figure 7. Booster and orbiter in M&R facility.

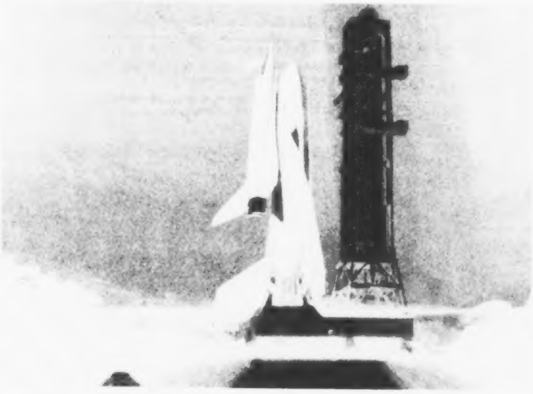


Figure 8. The Shuttle vehicle at liftoff.

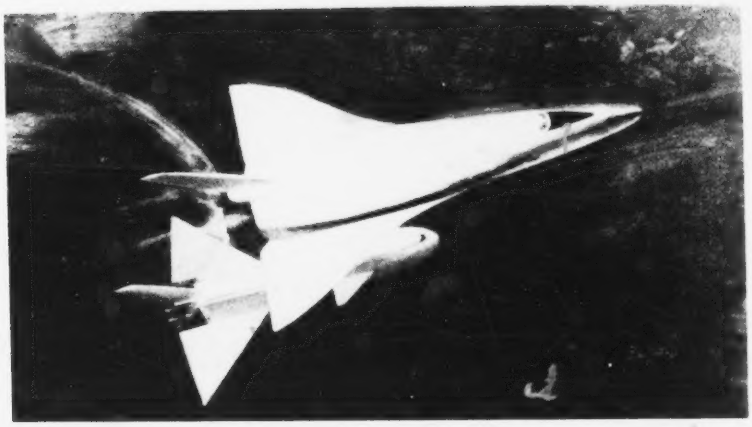


Figure 9. Booster and orbiter at separation stage.

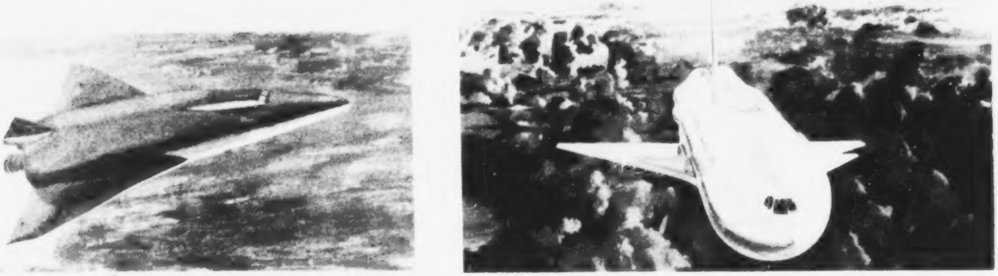


Figure 10. Completed separation of booster and orbiter.

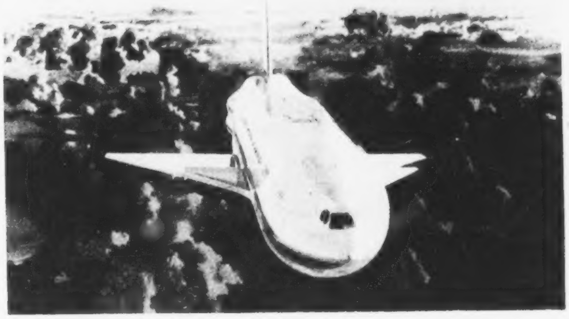


Figure 11. Booster during cruiseback to launch site.

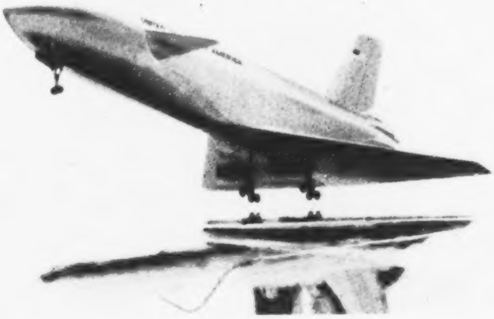


Figure 12. Booster at landing.

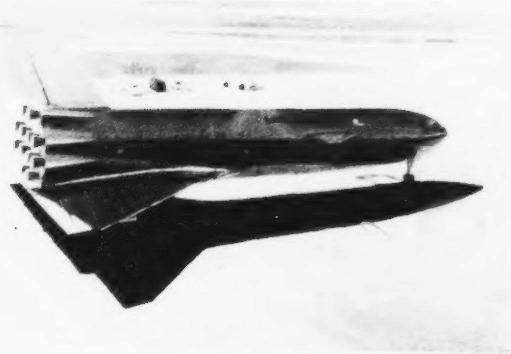


Figure 13. Booster in safing area.

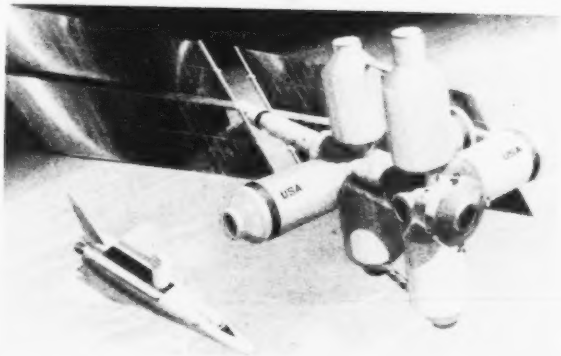


Figure 14. Orbiter unloading payload at Space Station.

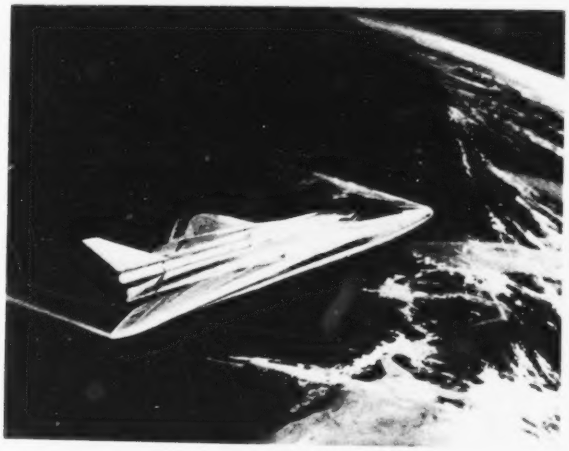


Figure 15. Orbiter during entry.

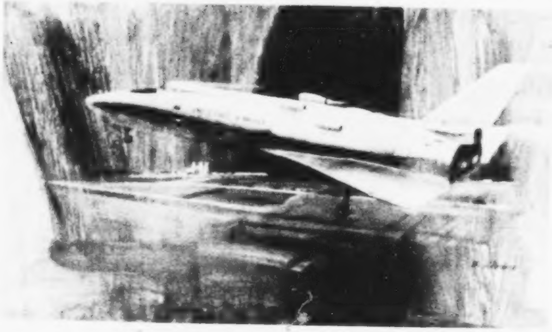


Figure 16. Orbiter at landing.

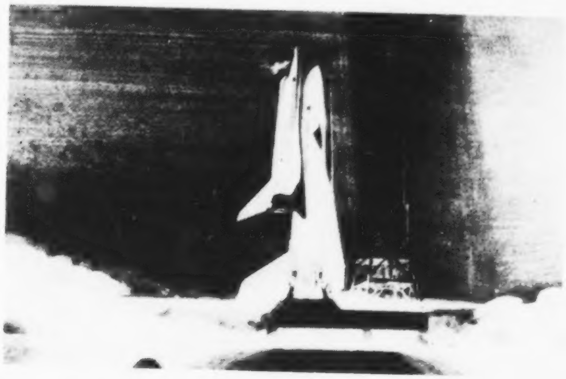
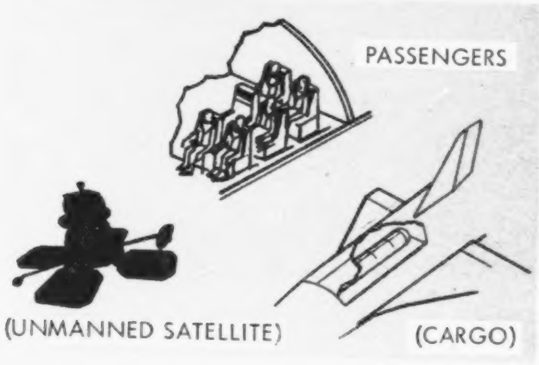


Figure 17. Two-stage launch vehicle.



PASSENGERS
(UNMANNED SATELLITE)
(CARGO)

Figure 18. Transports to or retrieves from orbit.

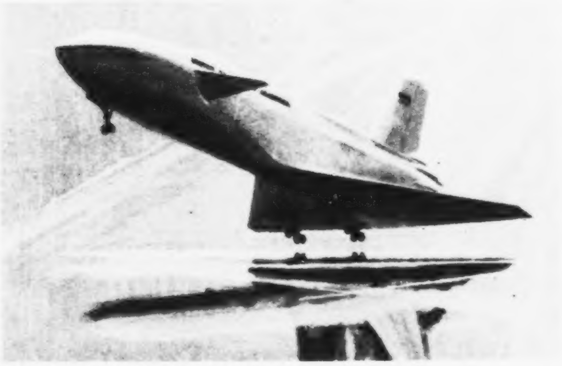


Figure 19. Services payloads and/or men on orbit.

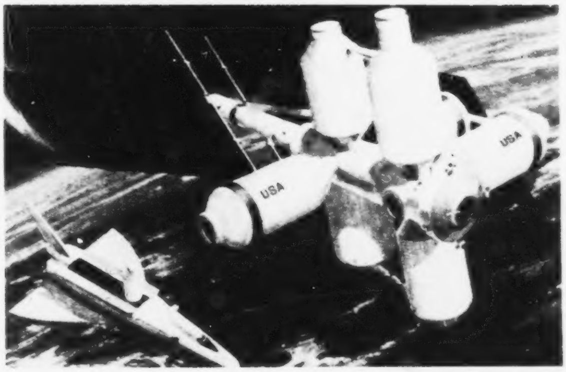


Figure 20. Reusable.

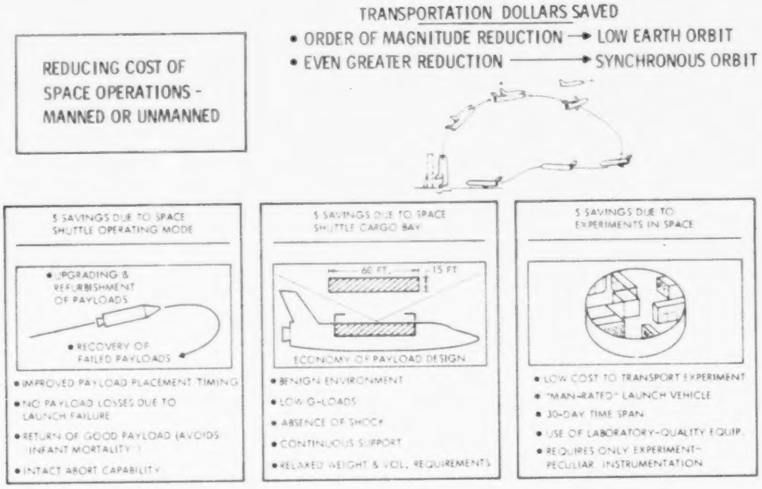

TRANSPORTATION DOLLARS SAVED
• ORDER OF MAGNITUDE REDUCTION → LOW EARTH ORBIT
• EVEN GREATER REDUCTION → SYNCHRONOUS ORBIT
REDUCING COST OF SPACE OPERATIONS - MANNED OR UNMANNED
$ SAVINGS DUE TO SPACE SHUTTLE OPERATING MODE
• UPGRADING & REFURBISHMENT OF PAYLOADS
• RECOVERY OF FAILED PAYLOADS
• IMPROVED PAYLOAD PLACEMENT TIMING
• NO PAYLOAD LOSSES DUE TO LAUNCH FAILURE
• RETURN OF GOOD PAYLOAD (AVOIDS INFANT MORTALITY )
• INTACT ABORT CAPABILITY
$ SAVINGS DUE TO SPACE SHUTTLE CARGO BAY
60 FT.
15 FT
ECONOMY OF PAYLOAD DESIGN
• BENIGN ENVIRONMENT
• LOW G-LOADS
• ABSENCE OF SHOCK
• CONTINUOUS SUPPORT
• RELAXED WEIGHT & VOL. REQUIREMENTS
$ SAVINGS DUE TO EXPERIMENTS IN SPACE
• LOW COST TO TRANSPORT EXPERIMENT
• "MAN-RATED" LAUNCH VEHICLE
• 30-DAY TIME SPAN
• USE OF LABORATORY-QUALITY EQUIP.
• REQUIRES ONLY EXPERIMENT-PECULIAR INSTRUMENTATION

Figure 21. Cost reduction of space operations.

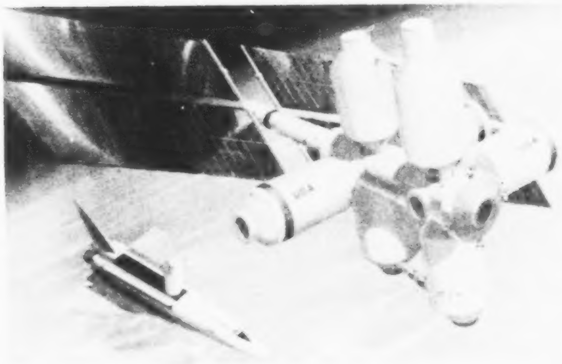


Figure 22. Space Station.

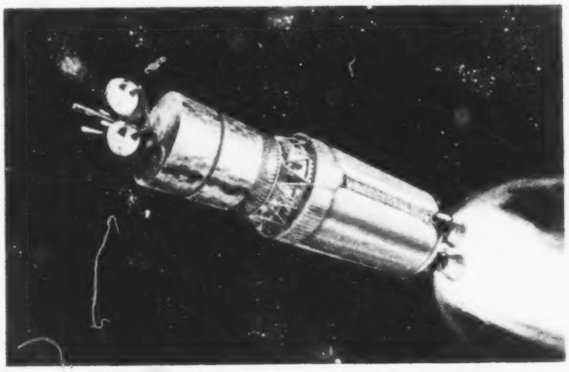


Figure 23. Space Tug.

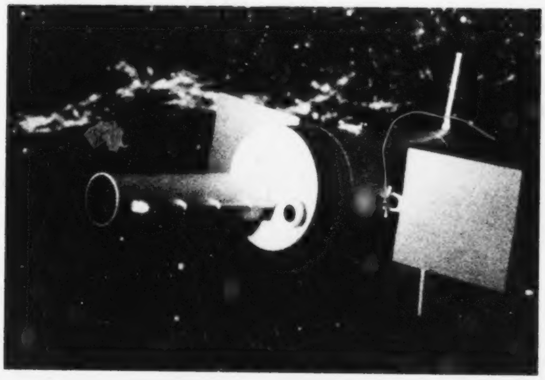


Figure 24. Research and Applications Modules (RAM).

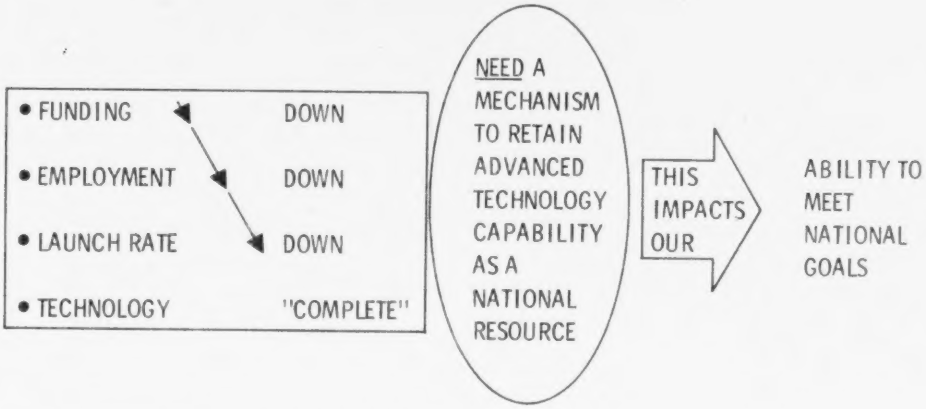

• FUNDING
DOWN
• EMPLOYMENT
DOWN
• LAUNCH RATE
DOWN
• TECHNOLOGY
"COMPLETE"
NEED A MECHANISM TO RETAIN ADVANCED TECHNOLOGY CAPABILITY AS A NATIONAL RESOURCE
THIS IMPACTS OUR
ABILITY TO MEET NATIONAL GOALS

Figure 25. Impact upon technological superiority.

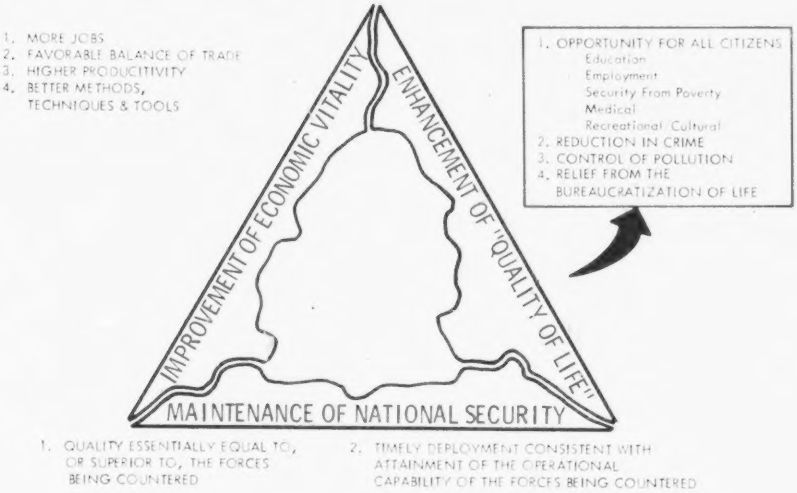
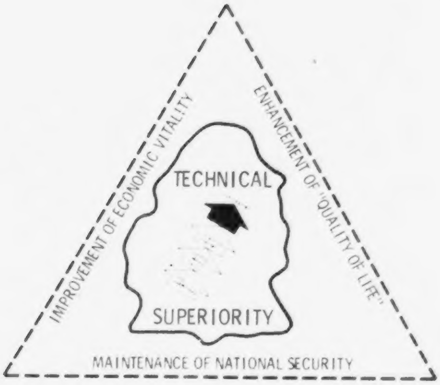

1. MORE JOBS
2. FAVORABLE BALANCE OF TRADE
3. HIGHER PRODUCITIVITY
4. BETTER METHODS, TECHNIQUES & TOOLS
IMPROVEMENT OF ECONOMIC VITALITY
ENHANCEMENT OF "QUALITY OF LIFE"
1. OPPORTUNITY FOR ALL CITIZENS
Education
Employment
Security From Poverty
Medical
Recreational/Cultural
2. REDUCTION IN CRIME
3. CONTROL OF POLLUTION
4. RELIEF FROM THE BUREAUCRATIZATION OF LIFE
MAINTENANCE OF NATIONAL SECURITY
1. QUALITY ESSENTIALLY EQUAL TO, OR SUPERIOR TO, THE FORCES BEING COUNTERED
2. TIMELY DEPLOYMENT CONSISTENT WITH ATTAINMENT OF THE OPERATIONAL CAPABILITY OF THE FORCES BEING COUNTERED

Figure 26. National goals.


IMPROVEMENT OF ECONOMIC VITALITY
ENHANCEMENT OF "QUALITY OF LIFE"
TECHNICAL
SUPERIORITY
MAINTENANCE OF NATIONAL SECURITY

- **EXPLORATORY RESEARCH CONDUCTED IN INTEREST OF ADVANCING TECHNICAL SUPERIORITY**
- **DEVELOPMENT & "REDUCTION TO PRACTICE" OF STATE-OF-THE-ART TECHNOLOGY**
- **IMPROVEMENT & EXTENSION OF PRESENT TECHNICAL SKILLS**
- **SHARPENING & REFURBISHMENT OF APPLIED TECHNICAL TOOLS**

Figure 27. Requirements and elements of technological superiority.

---

① BASIC RESEARCH ACROSS A BROAD FRONT

② APPLIED RESEARCH IN SELECTED AREAS THAT APPEAR TO HAVE PROMISING POTENTIAL

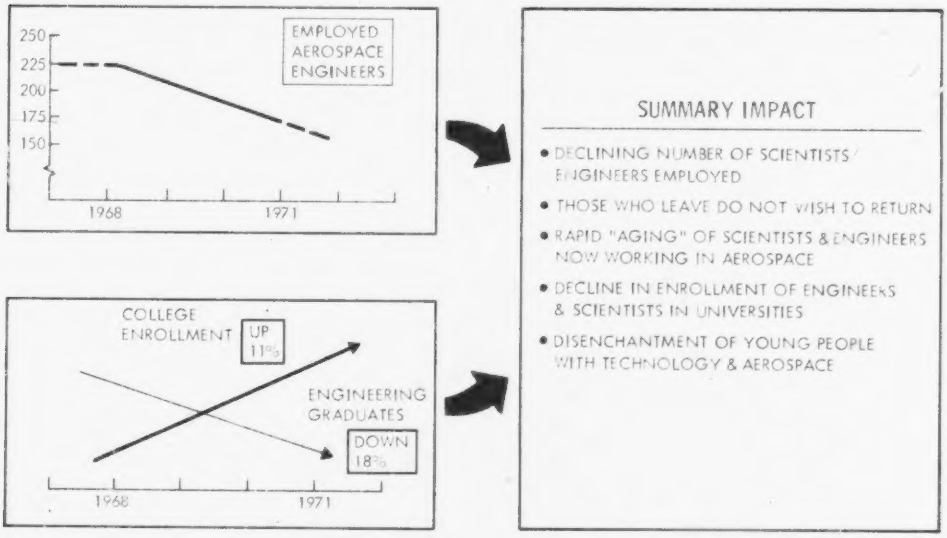
③ "NEW BLOOD" IN THE FORM OF A CONTINUING SUPPLY OF YOUNG SCIENTIST AND ENGINEERS

④ MULTIDISCIPLINARY MANAGEMENT/SCIENTIFIC/ENGINEERING/PRODUCTION TEAMS THAT INTEGRATE GOVERNMENT, UNIVERSITY, AND INDUSTRIAL ORGANIZATIONS AND MOTIVATE THEM TO ACHIEVE A COMMON GOAL

⑤ MAJOR AND TECHNICALLY CHALLENGING DEVELOPMENT PROGRAMS OF NATIONAL SCOPE

---

Figure 28. Maintenance of technological superiority.



SUMMARY IMPACT

- DECLINING NUMBER OF SCIENTISTS/ ENGINEERS EMPLOYED
- THOSE WHO LEAVE DO NOT WISH TO RETURN
- RAPID "AGING" OF SCIENTISTS & ENGINEERS NOW WORKING IN AEROSPACE
- DECLINE IN ENROLLMENT OF ENGINEERS & SCIENTISTS IN UNIVERSITIES
- DISENCHANTMENT OF YOUNG PEOPLE WITH TECHNOLOGY & AEROSPACE

Figure 29. Current trends in availability of scientists and engineers.

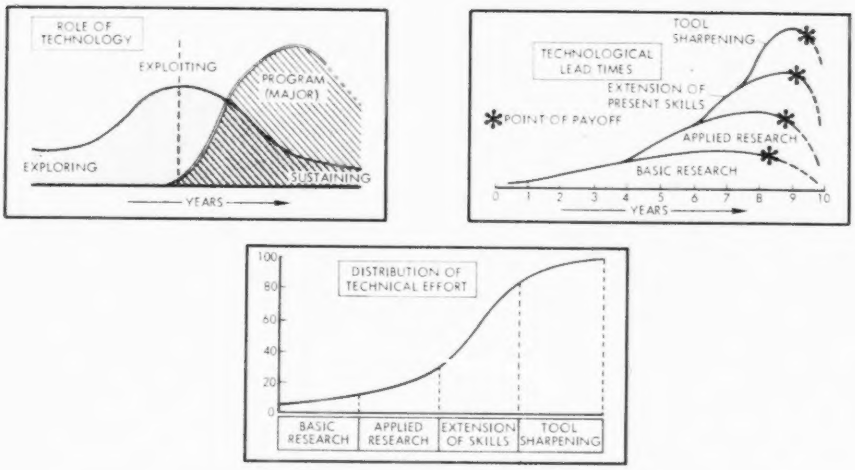


Figure 30. Three aspects of technology serving as the "cutting edge."

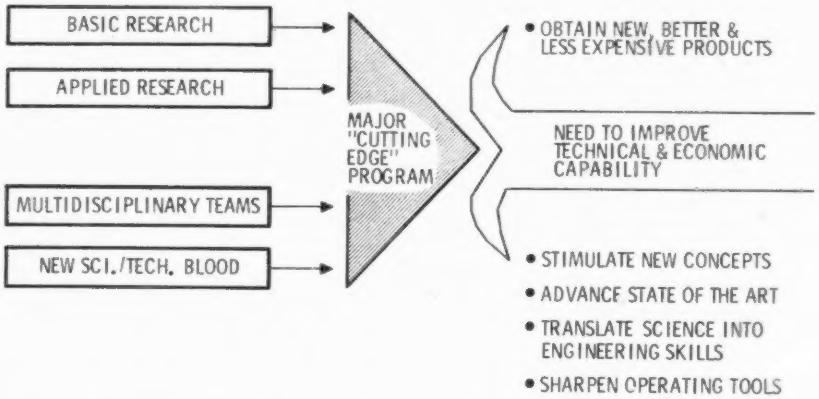

BASIC RESEARCH
APPLIED RESEARCH
MULTIDISCIPLINARY TEAMS
NEW SCI./TECH. BLOOD
MAJOR "CUTTING EDGE" PROGRAM
• OBTAIN NEW, BETTER & LESS EXPENSIVE PRODUCTS
NEED TO IMPROVE TECHNICAL & ECONOMIC CAPABILITY
• STIMULATE NEW CONCEPTS
• ADVANCE STATE OF THE ART
• TRANSLATE SCIENCE INTO ENGINEERING SKILLS
• SHARPEN OPERATING TOOLS

Figure 31. Integrating influence of "Cutting Edge" programs.

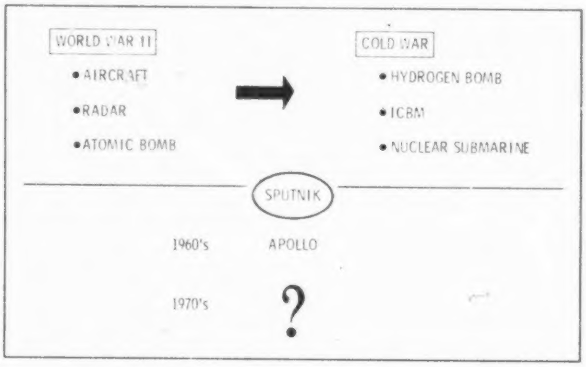
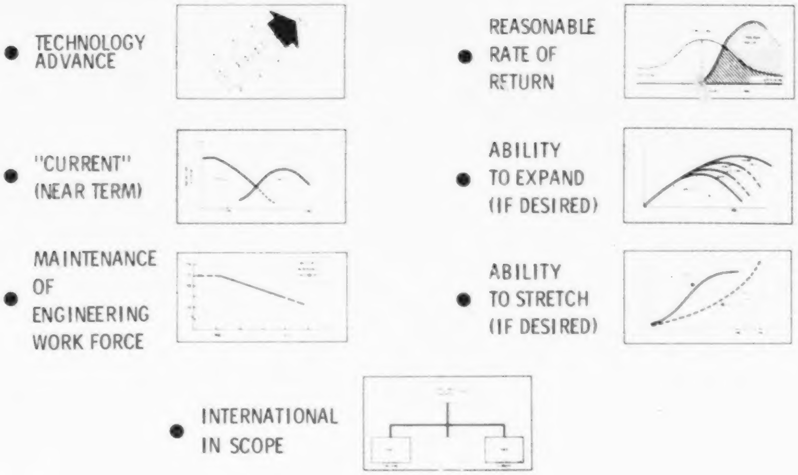

WORLD WAR II
• AIRCRAFT
• RADAR
• ATOMIC BOMB
COLD WAR
• HYDROGEN BOMB
• ICBM
• NUCLEAR SUBMARINE
SPUTNIK
1960's
APOLLO
1970's
?

Figure 32. Major "Cutting Edge" programs.

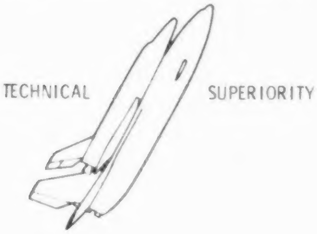


- TECHNOLOGY ADVANCE
- "CURRENT" (NEAR TERM)
- MAINTENANCE OF ENGINEERING WORK FORCE
- REASONABLE RATE OF RETURN
- ABILITY TO EXPAND (IF DESIRED)
- ABILITY TO STRETCH (IF DESIRED)
- INTERNATIONAL IN SCOPE

Figure 33. Required programs features.

- A MAJOR NEW PROGRAM MUST
  - ⁄ PRODUCE AN END PRODUCT THAT YIELDS DIRECT BENEFITS TO NATION
  - ⁄ PROVIDE A TECHNOLOGICAL INTEGRATING INFLUENCE
  - ⁄ SLOW DOWNWARD TREND IN NUMBERS OF EMPLOYED ENGINEERS & SCIENTISTS
  - ⁄ ATTRACT & RETURN YOUNG ENGINEERS & SCIENTISTS
  - ⁄ SLOW OR REVERSE THE RAPID "AGING" OF AEROSPACE TECHNICAL TEAMS
  - ⁄ SLOW SHARP DOWN-TREND IN ENROLLMENT IN SCIENCE & ENGINEERING SCHOOLS
  - ⁄ MAINTAIN MULTIDISCIPLINARY GOVERNMENT & INDUSTRY TEAMS

Figure 34. Required results of new "Cutting Edge" program.



SPACE SHUTTLE
IS THE KEYSTONE OF
FUTURE SPACE PROGRAMS

- REDUCING THE COST OF SPACE OPERATIONS – MANNED OR UNMANNED
- SPACE SHUTTLE: BASIC TO FUTURE SPACE DEVELOPMENT ACTIVITIES

Figure 35. Space Shuttle as keystone to future space operations.

- WILL STIMULATE ABOUT 20 BILLION OF DOMESTIC PRODUCTION
- WILL PROVIDE OVER 400,000 MANYEARS OF EMPLOYMENT IN AEROSPACE INDUSTRY
- WILL ALSO PROVIDE MORE THAN 280,000 MANYEARS OF NONAEROSPACE EMPLOYMENT REQUIRED TO SUPPORT PROGRAM
- WILL HELP U.S. BALANCE OF TRADE BY STIMULATING OUR HIGH TECHNOLOGY EXPORT INDUSTRIES
- WILL REQUIRE FEWER IMPORTS THAN WOULD A RESIDENTIAL HOUSING CONSTRUCTION PROGRAM OR AN INCREASE IN CONSUMER SPENDING OF COMPARABLE SIZE

Figure 36. Comparative impact of three environment programs.

| | CONSUMER SPENDING | SPACE SHUTTLE | RESIDENTIAL CONSTRUCTION |
|---|---|---|---|
| TOTAL PRODUCTION* | $19,100 | $20.000 | $ 16,500 |
| PER CENT AEROSPACE | 0% | 62% | 0% |
| MAJOR INDUSTRIES AFFECTED | • RETAIL TRADE<br>• REAL ESTATE<br>• WHOLESALE TRADE | • AIRCRAFT<br>• MISSILES & SPACE<br>• COMMUNICATIONS | • CONSTRUCTION<br>• LUMBER<br>• CEMENT/GYPSUM |
| BALANCE OF TRADE | | | |
| REQUIRED IMPORTS* | ✓ $435 | $300 | $430 |
| INDUCED EXPORTS | ✓ LOW | HIGH | LOW |

*1970 DOLLARS IN MILLIONS

TOTAL PURCHASES GENERATED

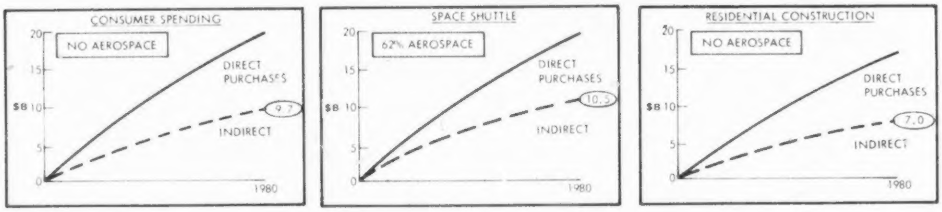


Figure 37. National economic benefits of the Space Shuttle programs.

# THE PATH TO GLORY UNTOLD

By Earl Hubbard
Space Philosopher
Lakeville, Connecticut

I would like to speak to you about freedom.

Freedom means the right to choose. To choose, you must have some sense of direction. You must know where you are going. To have a sense of direction, you must have some sense of meaning. To have a sense of meaning, you must have some sense of purpose.

Mankind today has no sense of purpose. Mankind today has no sense of meaning. Mankind today has no sense of direction. Mankind today is not free but is a prisoner of his own despair.

The challenge we face is how to emancipate mankind, and to do this we must discover a sense of purpose. If we can do this, we can then understand the meaning of our age, and through this understanding we can then discover a sense of direction, and in so doing, make mankind free to choose.

To do this, we need a new concept of genesis. Today there is revealed in the theater of mankind's awareness a new concept of the genesis of mankind as revealed by science. This genesis begins with a super nova.

A super nova is a large star exploding. Prior to this explosion, and after it has consumed most of the hydrogen and most of the helium of which it is composed, it collapses toward its center. It is in this collapse that there is created a crucible, and within this crucible there is evolved 1 percent of the elements that comprise the material universe.

So far as we know, the material universe is comprised of 90 percent hydrogen, 9 percent helium, and all the other elements make up 1 percent. This 1 percent is created in the crucible of a collapsing star.

There is, then, the explosion which radiates out into the universe in all the colors of the rainbow. In this majestic moment there is heralded a new event. The universe is, in effect, told that something new and something that is needed is coming. We are aware we are witnessing a cosmic conception, for the debris of this ecstasy fertilizes the recumbent figure of a hydrogen cloud which can stretch for trillions of miles long and may be trillions of miles wide.

As we watch, we see, condensed out of this hydrogen cloud, cottony balls of gas which then further condense into a sun with orbiting planets.

One of these planets, the one we call earth, appears to be covered with water. If we were to follow a beam of light from the sun into the depths of this primeval sea, we might see quaking at the end of this point of light, provided we had a microscope, something that looks like an amoeba. Then if we could compress eons of time into seconds, we would see this amoeba-like cell divide and subdivide. It might appear to join other cells to make larger bodies that swim.

We would see one of these bodies crawl from the water onto land, and walk, and run, and climb, and fly.

We would see land masses heave up and buckle into ridges of mountain ranges. We would see large glacial ice masses sculpt valleys and lake beds out of the surface of the earth.

Then we would discern a form of energy we would recognize, identify with, and call man.

Remember, all that has occurred has occurred with the same basic building blocks of energy. The building blocks have not changed, but the forms which are built with these building blocks have changed and have changed constantly.

This final form of energy on this earth, man, is the first form to speak. We do not understand its first words, but they appear in elegant drawings on the walls of caves. The first words we do understand are in the writing of cuneiform and hieroglyphics, and what they say, they say clearly. They say we seek God, meaning, and purpose.

Within the brief span that we call history, this form of energy pursues this search, and in the process develops all that we call culture.

The effect is synthesis, for it takes all the other forms of energy of which this earth is comprised, such as iron, coal, water, wood, and synthesizes them into steel, homes, and books.

Up until now, we have seen this highly motivated form of energy build this culture. We have heard it speak, but still we do not understand the meaning; what is the purpose? Finally at one point, if we watch very closely, we might see something leave the earth and land on the moon. At that point, the meaning is clear, for the meaning is birth and the purpose of all that has occurred on this earth is clear. The purpose has been to build a body capable of birth.

We recognize that within this brief span of history we have watched man synthesize all other forms of earthly energy into a body capable of birth, and that this synthesis occurred through the search for God, purpose, and meaning. The effect of this search has been that a cultural body, mankind, has been built and has now outgrown this earth.

All mankind's problems are growth problems.

Pollution is a growth problem.

Population is a growth problem.

War is a growth problem.

Drug addiction is a growth problem.

The problem is mankind has outgrown this earth. The meaning is mankind is being born. Mankind is not sick. Mankind is being born.

The effect is that mankind is no longer needed on this earth, any more than a baby is needed in the womb at birth. Mankind must now know that the meaning of the present is birth, that the meaning of the past was to build a body capable of birth. He must be aware that there is a sequence that preceded his birth, a nonrepetitive sequence of unique events that stretch from a super nova fertilizing a hydrogen cloud, to Armstrong's foot on the moon. Each event differs from those that flank it and each event is a synthesis of those that precede it. We see no repetition — no circular sequence. What we do see is a consistent purpose made manifest in a sequence of constant change.

Mankind may, therefore, have a sense of purpose, for he is part of this ever-evolving purpose. He can understand the meaning of his age as being birth.

To have a sense of direction, mankind must understand the difference between a prenatal existence and a postnatal existence. This difference can be best described in one word — conception.

A baby in the womb cannot conceive, but once born, it gains this capacity, not only to conceive sexually, but culturally.

Mankind, today, is between prenatal history and postnatal history, and before him, there is the Moon and Mars, two planets which await his capacity for conception, the conception of new worlds.

In accepting this capacity for conception, mankind will be accepting a range of choices inconceivable in the womb, inconceivable in prenatal history. Mankind, in accepting his birth, will be accepting a freedom of choice beyond anything he has ever dreamed of or imagined.

If freedom means the right to choose, then accepting his own birth will be accepting a new freedom of choice — the awe-inspiring freedom to conceive.

Can there be a choice between accepting or rejecting our own birth? No. To reject our own birth is to reject freedom of choice, this cosmos as a purposeful universe, the meaning of the present as being birth, the meaning of the past as being the building of a body capable of birth, claiming mankind has no sense of direction, and claiming mankind is not needed in the universe. To reject our own birth is to accept death. And the process of this acceptance on this earth would be dictatorship, devolution, and death.

WHY?

In our recent studies of ecology we have discovered that to have clean water we have to clean up not only Lake Erie and the Mississippi, but also the Thames, the Seine, the Volga, the Yangtse, the seas around Japan, parts of the Mediterranean, indeed, parts of most of the bodies of water on this earth, because all bodies of water on this earth are part of one body of water. Therefore, to pollute part is, in effect, to pollute all. To have clean water on this earth, we must have some form of total control.

The same holds true for clean air and population control. We must have some form of total control.

The issue is not whether there will be some forms of total control, the issue is whether these forms of control will be voluntarily accepted by the peoples of this earth or whether they will have to be imposed. This issue is dependent on what you have to exchange for voluntary self-restraint. If you have a future to offer mankind, you can expect a voluntary acceptance of self-restraint. If you do not have a future to offer mankind, you cannot expect voluntary acceptance. Therefore, to have total control in a world without a future, you must impose these controls, and the method would be that of a dictatorship. It might begin as something like Plato's Republic, but it would quickly degenerate into a Stalinesque form of tyranny, for the objective would be devolution.

The objective in a world without a future would be to maintain a dying species on a dying planet, which would mean mankind would have to devolve.

No police force or armed services could hope to control a world population successfully. The method of control would have to be more insidious. Tranquilizers and chemicals for sterilization would be placed in the water system, and pacification programs would be carried by the communication system.

In a world without a future, the enemy is hope. To destroy hope, we would have to rewrite our histories, for the thread that runs through all history is the thread of hope.

The effect of this devolution would be the metamorphosis of man into a vegetable, and the ultimate goal would be death.

In a world without a future, we would have a death-oriented society, for death would mark the threshold to the future. All hope would lie beyond death.

In a world without a future, there would be no freedom, there would be no sense of direction, no sense of meaning, no sense of purpose, and no need for man.

In accepting our own birth, the reverse is true. In accepting our own birth, there is the freedom to build new worlds. There is the need for man to build them. There is the acceptance of the meaning of our age as birth, the sense of being part of a larger, ever-evolving purpose.

To conceive of new worlds on the Moon and Mars, we will need all and the best that people have to give.

Cybernation and automation can do any repetitive task, no matter how complex. Most industries on this earth are consumer industries and maintenance industries, and all these industries are repetitive. All these industries will one day be cybernated and automated. This means there is now a declining need for man to do repetitive tasks.

In a world without a future, this would be but one of many manifestations of a declining need for man. But for a world that is building new worlds, it is the emancipation of man to do this task. Machines can do what has been done, but on this earth only man can do what has never been done.

The meaning of cybernation and automation is the emancipation of mankind to assume the task of conceiving of new worlds on the Moon and Mars. This is comparable to our own bodies.

Our own bodies are cybernated and automated so that we do not have to say, "Eyes focus, ears listen, or heart beat." This is done for us by cybernation and automation. The effect is that our awareness is emancipated. We can look out and concern ourselves with other tasks.

This effect is now apparent for the body of mankind, for the maintenance tasks, essential for this body to turn its attention to the conception of new worlds, is now being taken over by cybernation and automation.

In accepting our own birth, in accepting our capacity to conceive of new worlds, we are accepting the need for man. No other challenge on this earth can make that claim.

If you go to the people of this earth and say we need you for pollution and population control, you must remember that they are the pollutants and the population. There are too many of them for this earth to sustain.

If you go to the people of this earth and say we need you for war control, you have to remember that in a world without a future, war would be the only dignified way of life and death for a proud people that would rather die fighting than die as a vegetable.

And you cannot go to the people of this earth and say we need you for drug control, for in a world without a future you do not need people.

Not to be needed is painful. Not to be needed for anything, for a capacity to procreate, to work, and to create, is unbearable, and drugs might assuage some of that pain.

But in a world without a future, what difference does it make? In a world without a future, what difference does anything make? It does not. For in a world without a future, life is meaningless.

This is not only the greatest age in the history of mankind, it is the greatest age in the history of this earth. It is the culmination of a cosmic conception. It is the birth of something that is new and needed into the universe.

We are that something, and we are mankind. We are being born. We are between two worlds, between a prenatal and a postnatal existence, and between this earth and new worlds.

In this passage of birth, we require the faith that we are needed. In seeking birth, we seek some manifestation that will affirm this faith. Our faith must be that it is there waiting for us. This must be the faith of all babies.

Looking back from Armstrong's foot on the moon to the super nova that fertilized the hydrogen cloud, we see that all that was done, was needed, and all that was needed was done.

Could Armstrong have gone to the moon without the super nova; the hydrogen cloud; that first amoeba-like cell; that life that crawled from the sea, then walked, ran, climbed, and flew; those glacial masses that sculpted many of the valleys and lake beds of this earth; those land masses that heaved and buckled into ridges of mountain ranges; that early manifestation of energy we identify with and call "man;" those cave drawings, cuneiform, and hieroglyphics?

Looking back, our faith in a purposeful universe should be affirmed in witnessing that all that was done was needed, and all that was needed was done.

With birth, we will enter a new community, a galactic community. Like all babies, we can expect to be needed and to be loved by some part of this community. That is enough. For now we must rededicate ourselves to the search for freedom, and those that seek freedom, seek God, purpose, and meaning.

Let us continue this search on this path of glory untold.

# SESSION II
# FUNDAMENTAL BENEFITS OF THE SPACE PROGRAM

# APPLICATION OF NASA MANAGEMENT APPROACH TO SOLVE COMPLEX PROBLEMS ON EARTH

By John S. Potate
Director, Apollo Program Budget and Control
Office of Manned Space Flight
National Aeronautics and Space Administration

The subject of management has probably been written about as much as any other subject in the English language. One can obtain a host of books in any library on the subject. I think the reason for this is that management techniques must be applied to the particular job at hand and, therefore, there are many different approaches depending on the nature of the job and the management structure of an organization. Many fine management techniques have been developed in this country and NASA did not set out to invent new ones for Apollo, but rather they adapted the techniques to fit the particular needs of Apollo.

The subject of my talk is "Application of NASA Management Approach to Solve Complex Problems on Earth." Solving complex problems of any nature requires two major items. First, a commitment by responsible authorities is needed to solve the problem and a date for reaching that goal. Second, organization of the team and definition of the plan are required for achieving the goal. Of course, in Apollo we had a national commitment that President Kennedy established in May 1961 that this nation would land a man on the moon and return him safely to earth in the decade of the sixties. NASA then proceeded to organize a government, industry, and university team which, at its peak, involved 400 000 people, hundreds of universities, and 20 000 special industrial companies.

I would like to discuss with you in a short time what I consider the key elements of the management approach that NASA used for the Apollo program. I will concern myself with the management approach in the program planning and control area which is the heart of any program management system. Time will not permit me to discuss the management approach for other systems which are used in Apollo in managing the pure technical aspects of the programs, such as engineering specification systems, configuration management systems, reliability and quality systems, and others primarily concerned with obtaining a quality product in the configuration necessary to meet program objectives.

I have listed in Figure 1 four key elements in the management approach taken for program planning and control in Apollo. First, you must develop a good program or project plan. The level of detail must provide good understanding of the job to be done. Various techniques have been used to break down the job — familiar names, such as work breakdown structures, are commonly used on most projects. The important thing is to develop this structure so that there is a clear understanding of the job from the worker up through top management. The elements of the plan must allow efficient monitoring of schedules and cost progress. This is a difficult task to achieve since there are many scheduling techniques and cost accrual systems. Once you have developed a detailed plan for a large program or project, it is so voluminous that management cannot review all activities in the time available. Therefore, the detail plan must be summarized in levels so that problem areas can be readily identified and management attention can focus directly on the problem areas and not be hindered by constant and voluminous status reviews on tasks that are proceeding smoothly.

The second key element I have chosen is titled "manage by exception." This means simply that management must apply the greatest attention to those areas of highest criticality identified by the scheduling and cost systems. I think this is the key element in our management approach because, for a large system, the most difficult task is to use the management talent in the most effective manner.

The third element is titled "establishing a competitive attitude among organizations." This can be done in many ways. One of the most effective methods we have used is to list critical problem areas and display them in an area visible to all, with the organization and individual manager responsible for the problem.

The fourth element is titled "audit systems on a frequent basis." It almost goes without saying that the output of a system is certainly no better than the input. Management, down to the lowest level of supervision, must constantly audit the management procedures and techniques to assure that the job is being carried out in accordance with these procedures and techniques. For example, a person in an organization can, with all good intentions, perform a task different from the established procedures because he feels: "Well, that change really would not affect anything, and this certainly is a better way to do the job." He does not recognize that the procedures have been developed and reviewed by levels of management as the best way to do the job. Certainly the employee should identify to management those areas where he feels the procedure could be improved. Another example would be status information. Your system reports a piece of equipment is installed, so you schedule the next item of work and find that the status was erroneous. In summary, what I am saying is that management mistakes can be made based on bad information from a system. Therefore, it is most important to audit your systems on a frequent basis to prevent problems before they occur. Another note here — walkthroughs and general site reviews by top management are a tremendous boost to worker morale.

Now, I would like to illustrate this management approach to program planning and control by reviewing with you the Saturn V site activation of Launch Complex 39 located at Cape Kennedy, Florida, which is used to launch the Apollo/Saturn V vehicles. I have chosen this site activation task to illustrate the management approach but I could have well chosen many other complex Apollo tasks that all had to be accomplished on time and within cost to support the success of Apollo, such as the development of the Saturn V launch vehicle, development of the spacecraft Command and Service Module and Lunar Module (CSM and LM), and the many experiments and other equipment that support the launch vehicle and spacecraft systems. I also chose the site activation task because of my personal involvement, and this element of the Apollo program had by far the greatest number of external interfaces. All of the hardware had to come together at Kennedy. First, I think it is in order for me to go through, briefly, the major facilities involved in Launch Complex 39 and discuss briefly the mobile concept so that you understand the complex task which confronted NASA.

In previous missile programs, the conventional method of launch preparation was to conduct assembly, checkout, and launch operations from a fixed site, that is the launch pad. One of the major drawbacks to the fixed-site concept is that the pad is occupied for long periods of time while space vehicles are assembled and checked out for launch. The mobile concept allows you to check out the space vehicle in a building under better controlled conditions and then move the entire vehicle with its accompanying launch stand to the pad for final checkout and launch. This allows you to plan more closely spaced launches, which gave NASA a much more flexible launch system to meet the challenges of Apollo and future programs.

The Vehicle Assembly Building (VAB) which is used to assemble and check out the Saturn V space vehicles is the heart of Launch Complex 39 (Fig. 2). This building consists of a high-bay area and a low-bay area and is approximately 525 ft high and 700 ft long. When the three Saturn V booster stages arrive at Launch Complex 39, the second and third stages undergo checkout in the low-bay area, then are erected on the first stage in the high-bay area.

Adjacent to the VAB is the Launch Control Center (LCC)(Fig. 3). The LCC houses the electronic brains that control the checkout of the space vehicle (there are over 500 consoles and displays in the LCC). The total checkout and launch of the Saturn V vehicles is controlled from this center.

Perhaps the most unusual facility in the launch complex is the mobile launcher or LUT which weighs in excess of 12 million pounds (Fig. 4). This facility provides the launch stand and the equipment for support of the preflight checkout and servicing of the special facilities. This entire structure, along with the erected space vehicle, is transported from the VAB to the launch pad with the crawler transporter.

The transporter weighs nearly 6 million pounds and is capable of supporting over 12 million pounds (Fig. 5).

The launch pad shown is roughly octagonal and covers an area of about 0.5 square mile (Fig. 6). Adjacent facilities store propellants and gases for servicing the Saturn V vehicle.

The 402-ft mobile service structure (Fig. 7) permits 360-deg access to the space vehicle while it is at the pad. The mobile service structure is transported to the pad for mating with the space vehicle. The mobile service structure stays in position at the launch pad until approximately 15 hours before launch when it is removed and placed back in its erection area.

Figure 8 shows the total complex with the space vehicle in configuration for launch.

Figure 9 depicts the organizational relationships for the site activation effort. To provide centralized management of the site activation effort, a site activation control center was organized and located in the LCC in an unused firing room.

Figure 10 is a pictorial view of the control center which consists of four functional areas. Number 1 is the Site Activation Board meeting area which also displays the master management information. Areas 2 and 3 house the detail plans and personnel from contractors (13 aerospace, 10-15 crafts) and three NASA Centers — KSC, MSFC, and MSC. The fourth area is an audiovisual support area. Let me summarize the scope of the site activation effort. Over 63 000 items of equipment had to be installed and checked out. In addition, over 60 000 individual cables, connecting the various facilities within the launch complex, had to be installed and checked out. All of this had to be done in a very finite sequence.

NASA selected the PERT system as the primary planning technique. PERT, which stands for Program Evaluation and Review Technique, had been used by the Navy on the Polaris program. It also had been used on other programs. NASA modified this system to its specific needs. Figure 11 outlines the PERT system used for Launch Complex 39. The PERT system is simply a logic diagram outlining all tasks to be done in their proper sequence. As I mentioned earlier, one of the major management tasks is to summarize the detail plan into levels. We choose three levels of summarization. The detail plan consisted of 40 000 separate activities, which were summarized into approximately 7500 activities, and then further summarized into a master level of approximately 150 events. The numbers shown on the chart indicate the traceability between the Level B and Level C networks.

The particular event number of the Level B and Level C networks were identical. One activity on the Level B network represented up to 20 activities on the Level C network. This technique of summarization and unique traceability was a unique adaptation by NASA of several management techniques. The PERT system allowed management to identify the most critical problems by analyzing the output of the Level B network. The output consisted of a computer calculation and listing of all activity paths that were behind schedule in the order of criticality.

Figure 12 depicts a summary output of the Level B network. As you can see, the activity paths are listed in order of criticality. Once the problems were identified through the Level B network, management then went to the Level C network which contained the detail activities that were causing the problem. A review of the detail activities would result in a workaround method or resequencing the activities to eliminate the problem area.

One of the important systems supporting the PERT system was the equipment record system (Fig. 13). This system provided rapid status of the delivery of over 123 000 items of cables and equipment. The delivery status was then fed into the PERT system which determined if the delivery date would meet its required date. If not, steps were taken to improve the delivery status or resequence the project plan to accept a later delivery.

Figure 14 ties in with my earlier statement concerning establishing a competitive attitude among organizations. We used a master problem display in the control center. This display listed the 10 most critical problems in site activation and identified the responsible contractor and manager. This type of display was most effective. There was a tremendous competition among contractors and organizations to keep off the problem board.

I would like to close my presentation with the following thoughts. Large complex problems can be solved with a good systems approach, which I feel the Apollo program has demonstrated. The systems approach simply means you make all elements and disciplines belong to a total system which must function as a team to achieve a common goal. Unfortunately, many government-industry-university elements and disciplines have not had to operate in this environment in their past work. I feel it is paramount that we change this if we hope to solve other complex problems in the future. There is one point I did not mention thus far: that is that any successful management approach must have, above all, good people. There is no substitute.

- DEVELOP A GOOD PROGRAM OR PROJECT PLAN
  - LEVEL OF DETAIL MUST PROVIDE GOOD UNDERSTANDING OF JOB TO BE DONE
  - ELEMENTS OF PLAN MUST BE CHOSEN TO ALLOW EFFECTIVE MONITORING OF SCHEDULE AND COST PROGRESS
  - DETAILED PLANS FOR EACH ORGANIZATION OR TASK MUST BE SUMMARIZED INTO SUMMARY PLANS SO THAT TOP MANAGEMENT ATTENTION CAN BE FOCUSED DIRECTLY ON PROBLEM AREAS AND IS NOT HINDERED BY CONSTANT AND VOLUMINOUS STATUS REVIEWS OF TASKS THAT ARE PROCEEDING SMOOTHLY
- MANAGE BY EXCEPTION
  - SCHEDULE AND COST SYSTEM MUST IDENTIFY PROBLEM AREAS IN ORDER OF CRITICALITY
  - MANAGEMENT MUST APPLY GREATEST ATTENTION TO AREAS OF HIGHEST CRITICALITY
- ESTABLISH COMPETITIVE ATTITUDE AMONG ORGANIZATIONS
  - IDENTIFY CRITICAL PROBLEM AREAS TO ORGANIZATIONS AND INDIVIDUAL MANAGERS
- AUDIT SYSTEMS ON FREQUENT BASIS
  - OUTPUT OF SYSTEM NO BETTER THAN INPUT

Figure 1. Management approach.

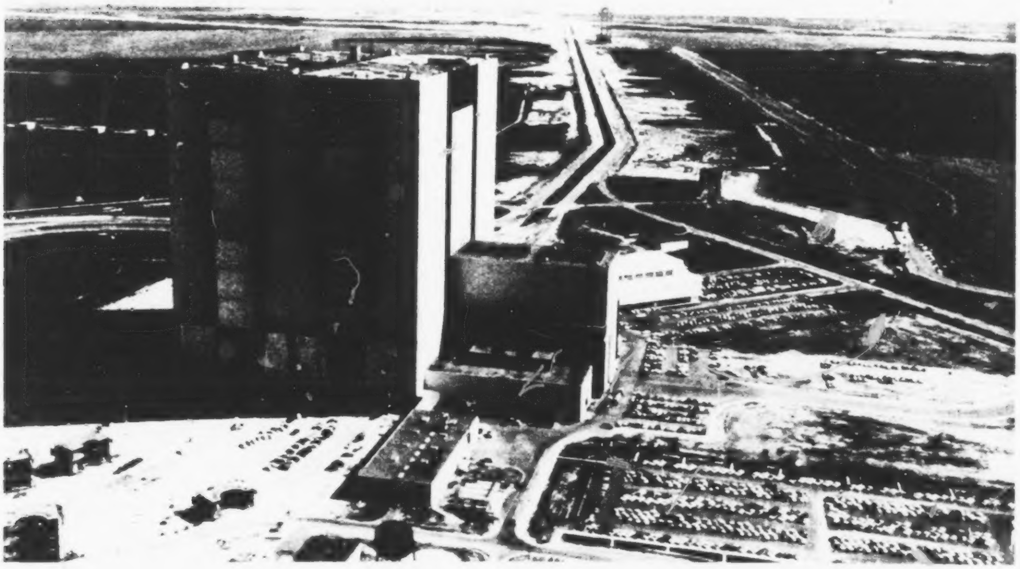


Figure 2. Vehicle Assembly Building.

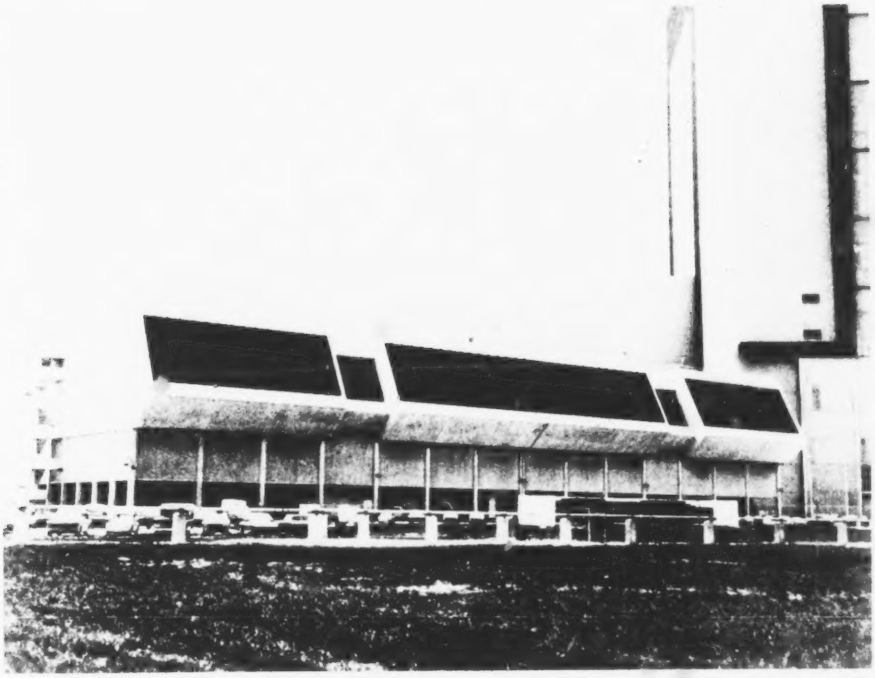


Figure 3. Launch Control Center.

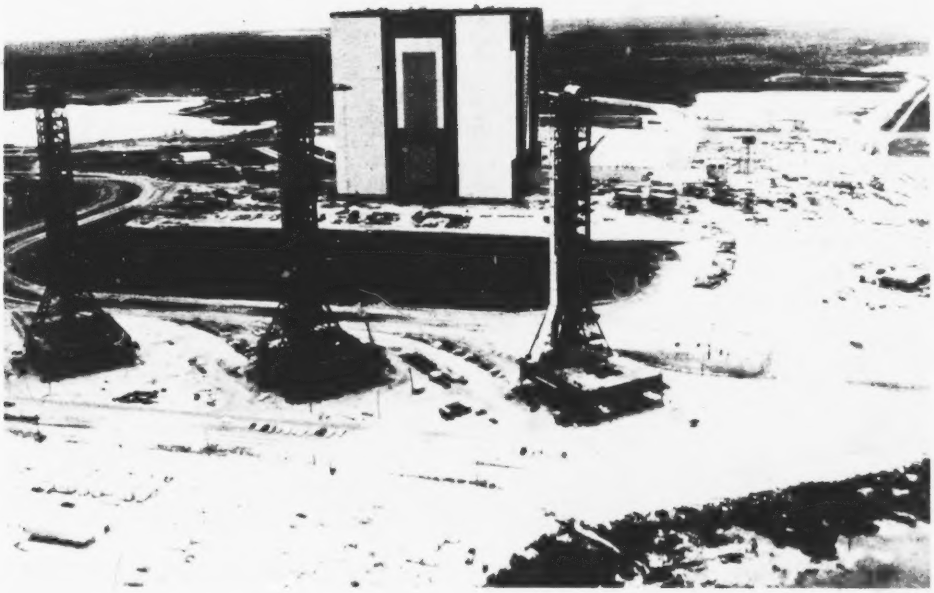


Figure 4. Mobile Launcher of LUT.

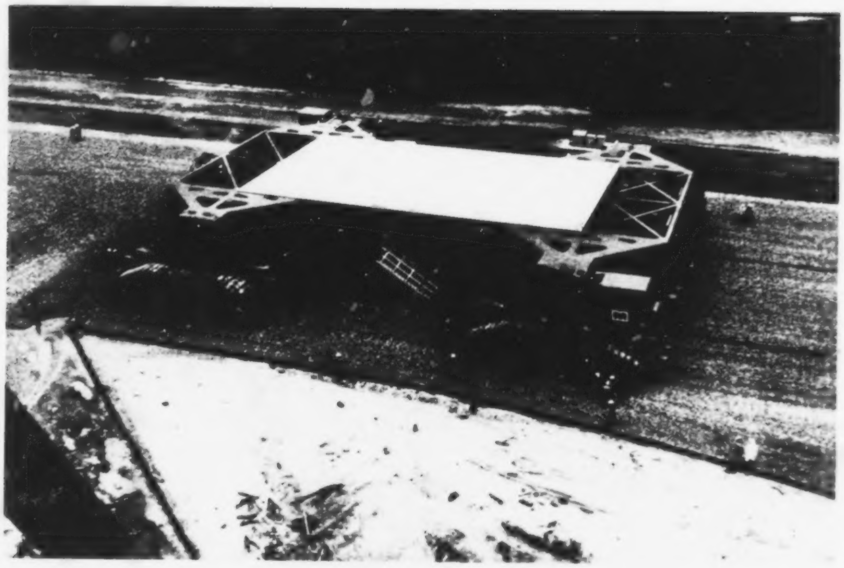


Figure 5. Transporter.

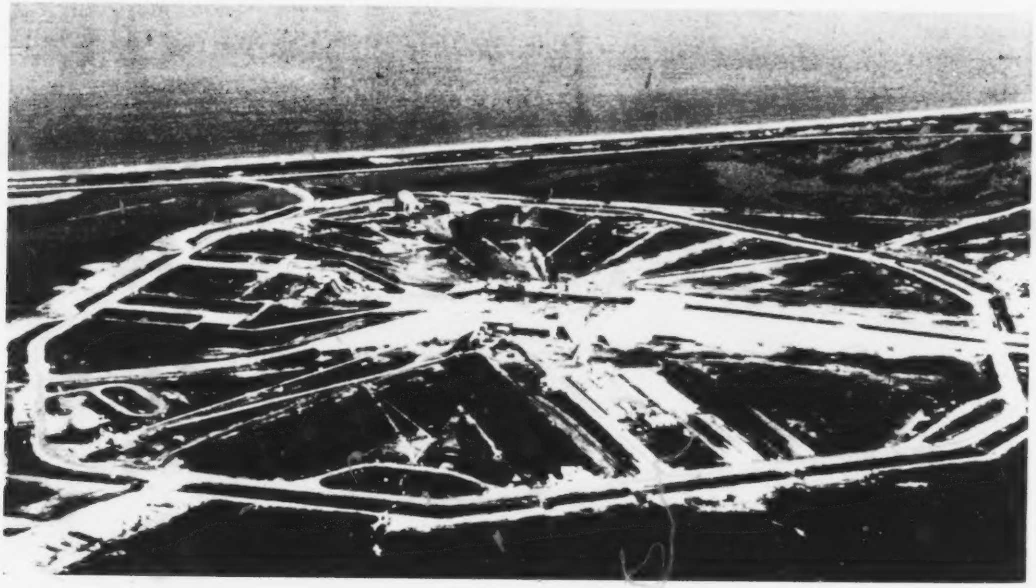


Figure 6. Launch pad.

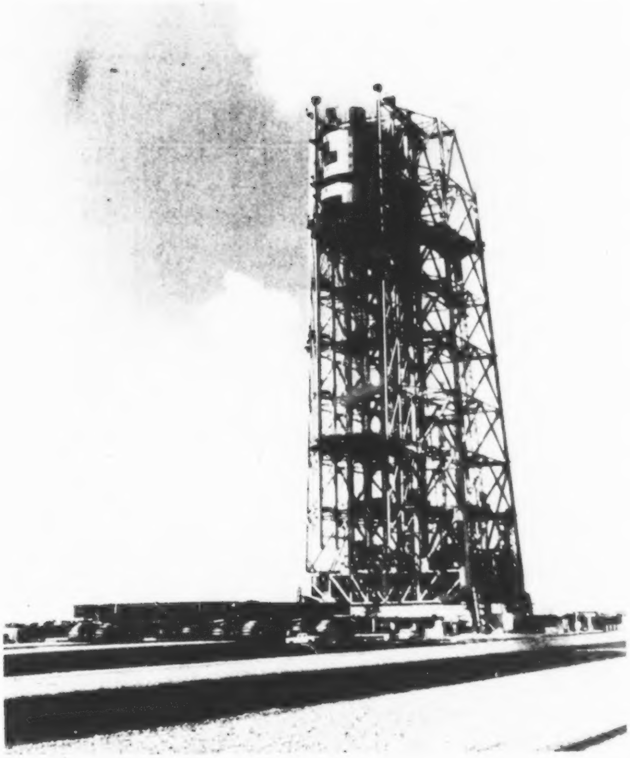


Figure 7. Mobile service structure.

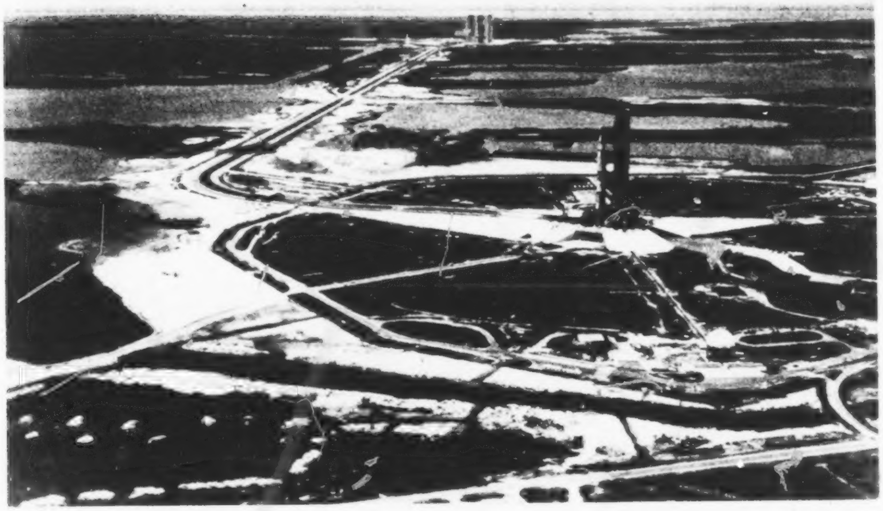


Figure 8. Total launch complex.

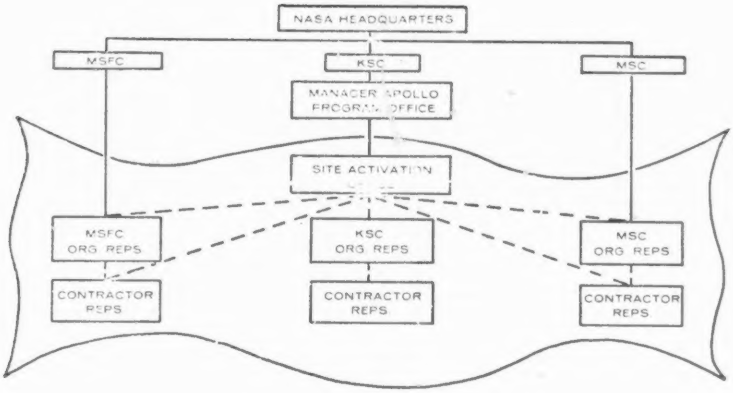

NASA HEADQUARTERS
MSFC
KSC
MSC
MANAGER APOLLO PROGRAM OFFICE
SITE ACTIVATION
MSFC ORG REPS
KSC ORG REPS
MSC ORG REPS
CONTRACTOR REPS
CONTRACTOR REPS
CONTRACTOR REPS

Figure 9. Site activation organizational relationships.

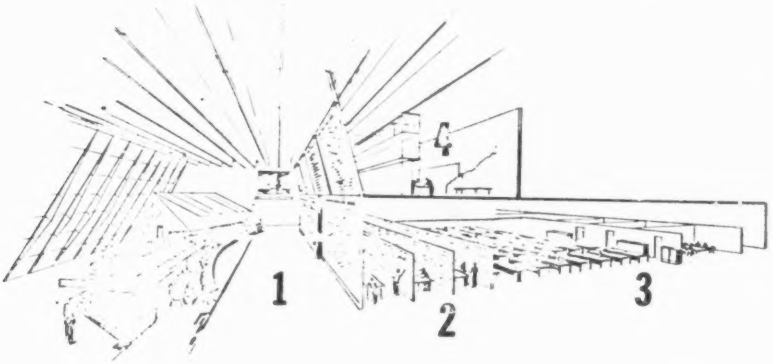


Figure 10. Program Control Center.

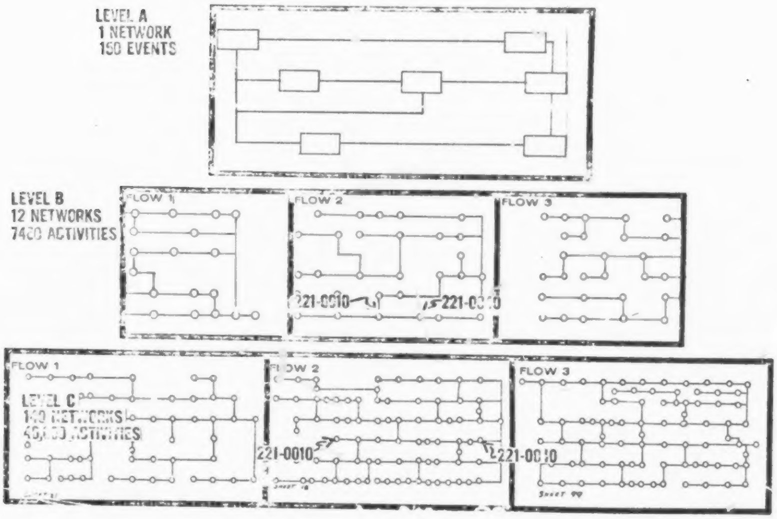

LEVEL A
1 NETWORK
150 EVENTS
LEVEL B
12 NETWORKS
7400 ACTIVITIES
FLOW 1
FLOW 2
FLOW 3
221-0010
221-0010
FLOW 1
LEVEL C
140 NETWORKS
40,000 ACTIVITIES
FLOW 2
FLOW 3
221-0010
221-0010

Figure 11. PERT systems.

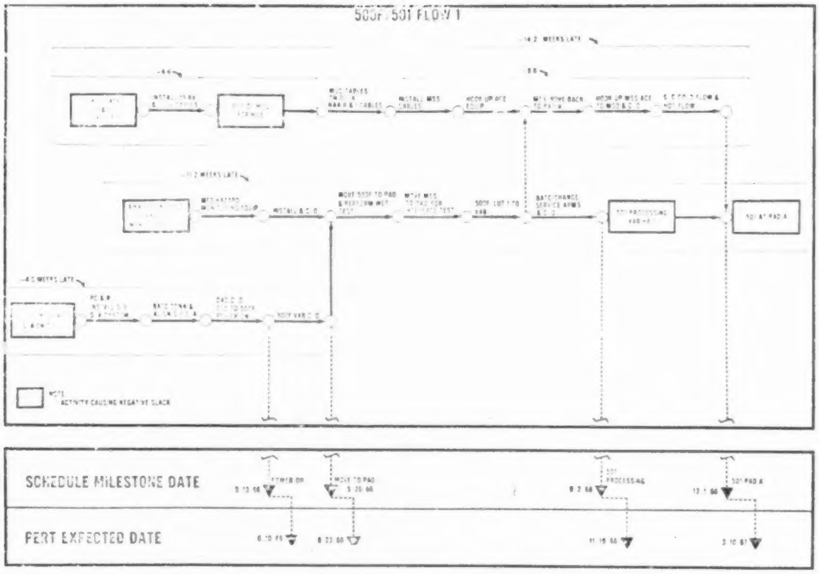

500F/501 FLOW 1
NOTE
ACTIVITY CAUSING NEGATIVE SLACK
SCHEDULE MILESTONE DATE
PERT EXPECTED DATE
POWER ON
MOVE TO PAD
501 PROCESSING
501 PAD A

Figure 12. Critica' path summary LC-39 site activation.

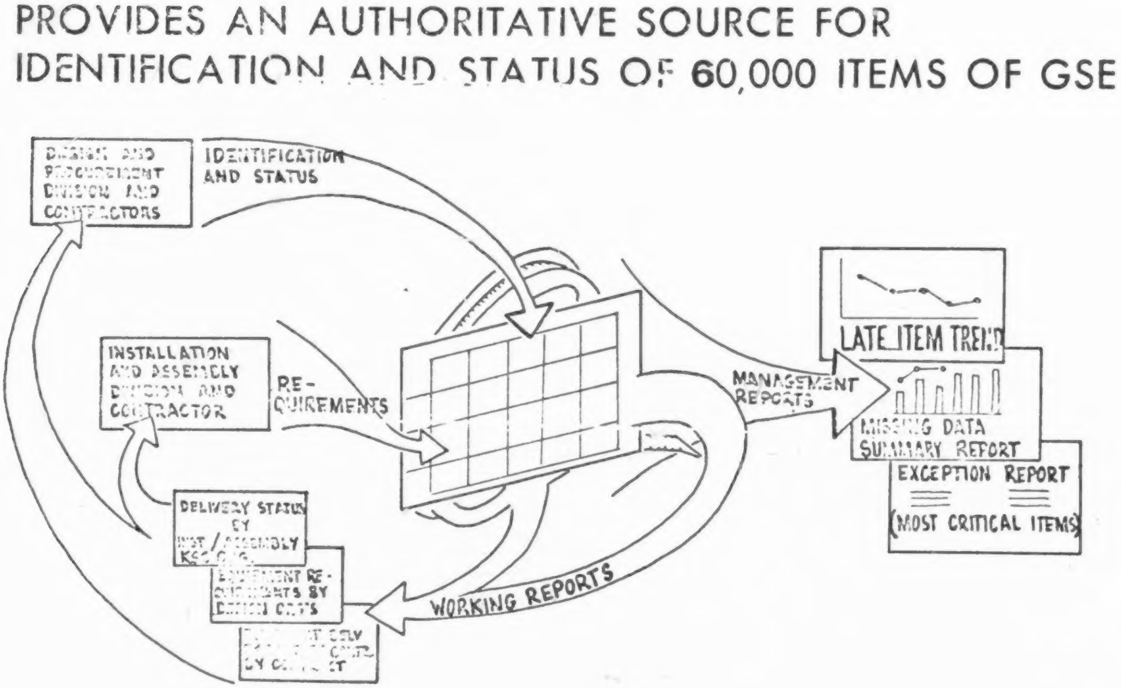

PROVIDES AN AUTHORITATIVE SOURCE FOR IDENTIFICATION AND STATUS OF 60,000 ITEMS OF GSE
DESIGN AND PROCUREMENT DIVISION AND CONTRACTORS
IDENTIFICATION AND STATUS
INSTALLATION AND ASSEMBLY DIVISION AND CONTRACTOR
RE-QUIREMENTS
MANAGEMENT REPORTS
LATE ITEM TREND
MISSING DATA SUMMARY REPORT
EXCEPTION REPORT
(MOST CRITICAL ITEMS)
DELIVERY STATUS BY INST/ASSEMBLY KSC ORG.
EQUIPMENT REQUIREMENTS BY DESIGN ORGS
BY CONTRACT
WORKING REPORTS

Figure 13. Equipment Record System.

| PROBLEM | SCHEDULE POSITION (SLACK) | CONTRACTOR | MANAGER |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |

Figure 14. Master problem display.

# OUR LEADERSHIP IN SCIENCE AND TECHNOLOGY AS PROVIDED BY THE NATIONAL SPACE PROGRAM

By Dr. Winston E. Kock
Chief Scientist, The Bendix Corporation

Science and technology have made outstanding contributions to the dynamic success of the U.S. as a world leader. Our strength in developing products derived from our science research, much of which is traceable directly to new requirements called for in the space program, has given us a position of prestige and influence throughout the world. Let us first view some generalizations and then some specific examples of how the space program has helped to provide this leadership. First, the space effort has showed how large teams of scientists and engineers of varied disciplines could work together. Next, it has called for unheard-of reliabilities in the component parts and systems. Through our success in achieving these reliabilities, our country has led others in applying that same reliability to our civilian technological needs. The space program has also demanded minimum weight and size, and in developing the present-day mini- and microcomponents used in the space efforts, we were able to lead in designing, for our civilian technologies, more compact electronics, for computers and many other technological devices. Next, through our space exploration, by satellites, by deep space probes, and on the moon itself, this country has led in acquiring a better understanding of our environment and other aspects of our world. Finally, because of our ability to develop the large rockets and boosters needed for the space program, we can now raise very heavy objects to orbits 22 000 miles above the earth, and thus be able to watch on television, worldwide events as they occur, transmitted over our communications satellites. As the U.S. National Academy of Sciences President, Philip Handler, recently asked: "What can be a more powerful instrument in the search for a lasting peace than live satellite television communications around the globe?"

Let us now examine some specific instances of how science advances and new technologies, created as a result of space research, have been able to perform a valuable role outside of the space program. We shall discuss here only creative results. We all know that there is always a short-term coupling between the spending of Federal money and the nation's economy. But when the Federal funds can be made to find their way into truly creative efforts, far greater long-time benefits have always resulted than when Federal money is simply used as an economic lever, as in various forms of Federal aid, in the use of Federal moneys for highways, etc., programs which all nations are undertaking.

The history of science and technology has shown that there are many examples where new technologies triggered vast areas of accomplishment in their wake extending over periods of time measured in decades. The Space Administration has been fully aware of science byproducts in its research and development activities and has been active in disseminating developments resulting from its scientific and technological programs. All significant scientific and technical papers and reports relevant to aeronautics and astronautics are identified. They include documents derived from NASA and its contractors, other branches of the Federal Government, and the aerospace activities of 40 foreign countries. The documents are microfilmed and indexed on tapes in data storage devices for quick access by interested users.

Probably the most important byproduct of the space program is the new knowledge gained in science. Historians tell us that there is an interplay among social needs, science, and technology. Each is necessary for progress in a technological society. Most scientists are agreed that advances in pure science are rapidly reflected in technological revolutions. Just as without the telescope, the science of modern astronomy would have been impossible, so without the rocket we could not now be pursuing science by sending instruments and men into the space environment.

New concepts and laws of science are much less predictable than are the applications which result from them. New observations made during space exploration can trigger chains of events extending well beyond our lifetimes and leading to unpredictably new scientific tools and concepts. Dr. Frederick Seitz, President of the Rockefeller University in New York, stated: "When future generations of mankind contemplate scientific knowledge made possible by the space program, they may well wonder what manner of men the doubters were." Space technology increases the likelihood of observing new phenomena heretofore unobserved. Man can now take his scientific instruments and living organisms to places in the solar system and to new environments where he was previously forbidden.

One of the oldest problems challenging scientists is the structure of the universe; the distribution of the elements, the evolution of the stars, the formation of the sun and planets, and the origin of the earth. All the information we had about the universe prior to 1957 came to us in the form of waves radiated from the surfaces of stars that reached our telescopes and spectrographs after passing through the earth's atmosphere. Unfortunately most of this star radiation is absorbed in the atmosphere and a remarkably small fraction reaches our instruments. Now, for the first time, we have the means of putting our instruments beyond this atmospheric curtain to record the full sweep of radiation.

A major stimulus to science and technology is produced by the extreme environment of outer space combined with the requirements for low weight, small size, and exceptional reliability. We had this combination of requirements in aircrafts in the past but they did not approach the severity of the requirements for space vehicles. Obtaining the needed realiability in such complex systems poses an extremely large departure from past viewpoints and practices. Engineers used to be satisfied with modest reliabilities; the space program has developed attitudes among engineers so that much higher reliabilities, approaching 100 percent, are possible.

The space program has also furnished a new stimulus to imagination and creativity among engineers. This has come about perhaps because of the complexity of the problems to be solved and the lack of past experience. Designers faced with a set of entirely new constraints and no experience on which to draw were able to exercise their creativity in ways that were heretofore impossible.

The space program, and particularly the Apollo program, represents a uniquely different problem of management of large technological systems. In the past, there have been some massive engineering developments, but in the space program there are only a few items of each kind constructed, their complexity is greater, and the reliability which is required exceeds that of the past. For this reason it has been necessary to develop a system of engineering management to specify what is wanted clearly and completely and to get it right the first time. The unusual successes in many space programs indicate that we are achieving higher levels of ability to develop, produce, and operate complex systems. There is a growing belief that the methods of systems analysis, systems engineering, and program management developed in the space program will have important application to social problems. Transportation, water management, medical services, ecology, and housing are areas where these methods should prove beneficial. It has been suggested that the gains in techniques for producing systems of ever-increasing reliability will eventually be worth many more times the cost of the space program.

Our space program has also been able to satisfy many of the needs of our society. Let me conclude, therefore, with a discussion of one outstanding example of how society the world over has benefited, and will continue to benefit in the decades to come, from a technological science development which is directly tied to space vehicles.

A satellite is uniquely qualified, by its line-of-sight feature, to be equivalent to a radio relay tower many thousands of miles high. It fulfills, therefore, the biggest difficulty of wideband microwave communications. Because of the earth's curvature, these signals are now relayed every 30 or 40 miles, a requirement which limited transmission to developed land areas such as those of the U.S. The several order-of-magnitude increment in relay tower height is, without question, one of the most significant advances in global communication technology. Accordingly, one of the greatest impacts of our space program is found in the field of communications. This is a consequence of our ability to place satellites in the one-revolution-per-day orbits called stationary orbits. Because the earth also rotates on its axis once every day, such satellites appear stationary with respect to the earth. Communications satellites are now "parked" in stationary orbits over both the Atlantic and Pacific Oceans, where they act as relays, receiving and sending television signals or hundreds of telephone conversations. It appears that such satellite links are much more economical than the earlier undersea cable links, which further could not transmit television. Improvements in communications are extremely important because in the U.S. communications is a big business, a really big business. Our long distance telephone calls alone total almost $5 billion a year. At this $5 billion per-year rate, if we could, for example, make twice as many calls at the same cost, we would be saving $5 billion a year, more than the space program is now costing us. Our overseas calls (not including Mexico and Canada) total almost a quarter of a billion dollars, and satellites now parked over the Atlantic and Pacific are already relaying a large fraction of these calls.

Now the economics for satellites for telephoning are rather startling. The wholesale charge to telephone companies of a transocean voice channel via satellite is only 10 cents per minute. So, our telephone costs are destined to come down. Furthermore, satellites are providing us with something heretofore unavailable — live television coverage of many worldwide events. Communications within nations are also due to benefit soon. In late 1970, COMSAT proposed a $114 million domestic U.S. communications satellite system to be leased to the American Telephone and Telegraph Company for a reported $29.5 million a year. Its capacity of 10 800 voice circuits results in this lease charge, for full usage, being equivalent to approximately one-half cent a minute for a cross-country, long distance call.

On September 18, 1969, the Indian Department of Atomic Energy and NASA signed a Memorandum of Understanding to conduct a joint instructional television experiment using the Applications Technology Satellite (ATS-F). This experiment will provide the technology to overcome India's lack of broadband telecommunication links throughout the country and disseminate instruction and information to rural, remote areas, where 80 percent of her population lives.

The Indian Government studied the cost and significance of establishing a powerful national mass communication television system using a synchronous satellite to link rural communities and distant centers of population. For further study, they installed community television receivers in 80 villages around Delhi. In this system many small villages will receive the signal directly from ATS-F. In densely populated areas, sets will receive a signal from local stations which rebroadcast the signal they receive from the spacecraft.

But we should not judge the value of our space research from the practical results alone, extensive as they may be. There may often be hidden values of far greater importance. As success breeds success, excellence breeds excellence, and the great demands for quality and excellence which the space program places on its equipment, its planning, and its functioning, these provide a magnet for attracting talented scientists and engineers to the program. The key to future advances in technology and to an advancing prosperity for our society will continue to be an emphasis on the search for new knowledge. Many critics of the space program have been saying that the funds spent for space would be better spent right here on earth. You probably know Wernher von Braun's story of the little old lady, sitting on her porch in her rocking chair. When asked if she was ever going to ride an airplane, she responded, "No siree, I'm just going to stay right here on earth and watch television, like the good Lord intended." Well, now she can watch worldwide television!

# SPIRITUAL IMPACTS OF THE SPACE PROGRAM ON THE WORLD

By Honorable Marvin Esch
U. S. House of Representatives
Committee on Science and Astronautics

Discussions of the space program and its benefits tend to concentrate on specific technological advances, on weather reporting systems, earth resources surveys, use of miniaturization, and so on. Those advancements are important indeed, but this paper is about less concrete, but no less important contributions that the space program has made to the human spirit, and to the ability of man to live in the world and with his fellow man.

Since 1945, and the devastation of Hiroshima, man's hope has deteriorated; man has lacked faith in his ability to control the forces of this horrible weapon. He has lacked faith in his ability to control his future and, indeed, to survive. There has been a desperate feeling that we somehow are careening toward disaster and that there is nothing else that we can do about it. We have all looked on hopelessly as riots have spread throughout our cities, as important political figures have been assassinated, as the war in Vietnam takes the lives of our young men despite our public protest, and as our cities have become more crowded, and even less livable.

Then suddenly and recently came the dramatic words, crackling through space, that people have landed on the moon. Nearly all the world was stunned by this dramatic announcement as we suddenly realized that, in the midst of all our difficulties, man had conquered a problem so complex that it was inconceivable to the individual. We realized, by devoting sufficient resources and talent, difficult problems could be solved, and it gave us hope; hope that we could accomplish other seemingly impossible tasks here on earth. As Astronaut Collins said, as he addressed the joint session of our Congress, following the first walk on the moon, "We cannot launch our planetary probes from a springboard of poverty and discrimination or unrest." Through that statement and through statements like that, we came to realize that the same kind of intensive national effort might solve these problems.

Is it not interesting that since the first moon walk, much of the discontentment and unrest has died down, and we are now not faced with summers of riots in our major cities? There is no obvious cause-and-effect relationship; however, I am convinced that there is some connection. The hope which inspired the space program and was inspired by that program has given us a new hope here on our planet, earth.

Equally significant has been the phenomenon that as man reached toward the stars, he suddenly gave a new perspective of himself and the world he lives in. In the words of Dr. Wernher von Braun, Apollo furthermore has altered the concepts we had of ourselves, of our earth, and of man's capabilities to guide events, if only slightly, to a new future, on a scale never thought possible before. The significance of these concepts is that they are not nearly merely national in scope; they embrace all humanity. As such, they tend to knit together man's mind and aspirations toward common goals for the benefit of all; not just to the advantage of some.

The view from another planet, the moon, brought hope to us that earth is the abode of all men, that it is unique in the solar system, and that we depend for existence on its slender resources of air, water, minerals, and plant life. To see earth as a complete and closed ecological system, in the black of space, was an emotional shock which shook us free of long-established purely parochial concerns. We suddenly realized how fragile and tenuous is our hold on life; not only human life but all life. For all we know, as of this moment, earth is the only habitat of living things in the universe, no matter how we may speculate the chances that are we are not alone and life exists elsewhere.

As I recall, Astronaut Bill Anders of Apollo VIII, in the midst of the first circumlunar voyage, talked about his home planet as a small blue-green ball, about the size of a Christmas tree ornament. Of course, Colonel Worden made a similar comment before a joint session of Congress, during his official welcome home after Apollo XV, when he commented on the oneness of the earth that we do not see from the ground; deep in space there are no visible boundaries nor can any differences be seen in race or religion or political beliefs. His point was that he and his fellow astronauts were a team of three, living in the spacecraft, Endeavor; a situation very similar to the billions of people living and working on the spacecraft, earth. His point was, just as our astronauts were required to work together to survive, we, here on earth, are faced with a similar struggle. I must say that I wish we earth-bound representatives were approaching our task with the same training, skill, knowledge, and cooperation of our spaceborne counterparts.

Let us just take stock, for a moment, of that spaceship, earth. Projections of the world population, growth, food and water supplies, power generation requirements, environmental pollution trends, and usage of the earth's resources, land and sea, indicate that within the next 100 years we will reach a point where the immediate survival of our planet will depend upon the careful and complete management of its environmental control system. Perhaps this frank and brutal assessment was an outgrowth of those comments by our astronauts. More important, and a vital contribution of their activity, will be to establish a technical base by which we can enter into this era of a man-dominated closed-loop environmental system with confidence in human survival. My point is that the goals of man's spaceflight, and for that matter, Apollo XV, were not directed toward idealistic or emotional objectives. Indeed, the goals of man's spaceflight are firmly tied to a critical national and world objective: our quality of life on this earth and survival itself. With that vision and with that confidence, which the space program has given us, mankind indeed can survive.

# INTRIGUE AND POTENTIAL OF SPACE EXPLORATION

By Dr. Hazel Losh
Professor Emeritus of Astronomy
The University of Michigan

Since astronomy is the oldest of the sciences, it stands to reason that this science has the greatest potential for advancement through space exploration.

From the dawn of intelligence, people have looked looked up at the heavens and have wondered and wondered and wondered — and I say that was the beginning of space exploration. At first they worshiped the sun, the heavens, especially the sun and the moon, for they realized that they depended upon the sun for light and heat by day, and upon the moon for light at night. You will find in the fourth chapter of Deuteronomy, the 19th verse, "And lest thy lift up thine eyes into heaven and when thy seek the sun and the moon and the stars, even all the rest of the heaven should be driven to worship them and serve them."

Also, we have the development of astrology. Of course, we have no use for astrology — it is pure fortune-telling. But it did serve a purpose in the development of astronomy. The ancient people saw that when certain objects were in the heavens, certain planets, things happened here on the earth — as a sort of echo of the heavens, as they thought. Today, we know that this is connected with seasons and positions, and does not have any direct influence as the ancients thought.

Astronomy was then used for practical purposes, time, calendar, and navigation. But all through the ages people have asked, "What does it all mean? Where are we in the universe? What is the position of man in this universe?"

At first the ancients thought the earth was at the center of everything. Man was supreme: earth was at the center and stationary. They had various ideas about the shape of the earth: i.e., flat, or saucer-shaped (because it had to have a rim or people would fall off), drum-shaped or log-shaped, but Pythagoras, in the sixth century B.C., believed in the sphericity of the earth. Now, I am sure, when I studied history and geography I thought that Columbus was the first person who thought the earth was round. However, Pythagoras, 2000 years before, had the idea of a spherical earth. In fact, Ptolemy had written the "Almagest" in A.D. 150; since it was the textbook that Columbus used in the University of Pavia, he was taught that the earth was a sphere. Little did Pythagoras or Columbus know that we would have astronauts photographing the moon and earth as round — as a sphere! You never know with these discoveries, what is going to happen 1 or 2000 years later.

The ancients tried to measure as best as they knew how. They did not have very much equipment, but did have the gnomon, a vertical stick. They measured the lengths of the shadows and were able to determine the winter solstice when the shadow was long, and the summer solstice when the shadow was short and the sun was highest in the sky. Halfway between the solstices we have Thales in the sixth century B.C., trying to measure the apparent diameter of the sun. He did not have a good timing device, but he had set up a ratio between the time when the western edge of the sun touched the western horizon and completely disappeared, and the time it took the sun to cross the sky; he got 1/720 of a circle. This was not bad; we still have a half degree today.

The ancients made measurements just as good as they could with the knowledge and equipment they had. Philolaus and other Pythagoreans, in the fifth century B.C., were very much interested in the moon; they thought there were lunar inhabitants, who were more intelligent, 15 times stronger, and 15 times more beautiful than people here on earth.

Copernicus was bold enough, in 1543, to take the earth out of the center and call it a planet like the other planets revolving around the sun. He was followed by Galileo, who brought about big advances in astronomy when, in 1609 and 1610, he started his telescopic observations. The story goes that the telescope had come in for military purposes and that Galileo succeeded in obtaining a telescope and turned it to the moon. It is somewhat questionable whether or not Galileo was the first person who did this, but he most certainly is credited with it. He saw the craters on the moon, those holes, but many people would not look through his instrument. They said, he put things in the tube: they said, if those holes are there they had to be filled with a crystal substance: because of its appearance the moon had to be smooth.

Galileo also turned the telescope to the Milky Way and saw that it was made up of stars. He did not realize what a bearing that fact would have on the structure of the galaxy later. He also looked at the sun where he saw sunspots. He discovered the four satellites of Jupiter. He was not able to make out the rings of Saturn but he thought there was something there and referred to them as "ears."

A contemporary of Galileo was Kepler, who stated his laws of planetary motion. Also, Sir Isaac Newton, in 1687 in the "Principia," stated his law of gravitation. How little did Kepler and Galileo, in the 17th century, realize what use would be made of that law in our space exploration through celestial mechanics. As celestial mechanics developed, we are coming up to the last century. At this point in time, photography is developing. The moon was photographed in 1840, the first star on July 17, 1850, and then we have spectroscopy. Spectroscopy proved to be very important to astronomy 100 years ago, but it is just as important today. In space astronomy, we send up spectrographs to analyze, and to find out what elements are there. I used to tell my students that they could change their little verse "Twinkle, twinkle, little star" to "Twinkle, twinkle, little star, need I wonder what you are?" With my spectroscope I can see helium and hydrogen. Up to that time you could look through the telescope and photograph objects, but you could not find out what they were made of: it took the spectrograph to analyze that light.

We come on up into our century, and, of course, as the telescopes got bigger, we found that the atmosphere was troublesome. "Bad seeing," we call it is astronomy when we are talking about this. The bigger the telescope was, the worse the "seeing," because the motion of the atmosphere was magnified. So we have our big telescopes, such as those at Mt. Palomar and Mt. Wilson, up on mountaintops to get as far as possible above the atmosphere. It was found that for the spectrograph also, the atmosphere was very troublesome, because there was only a very small portion of that spectrum that showed up: about 3900 to 7000 Å. All that ultraviolet and infrared could not be seen.

Briefly, that is the history of astronomy before space astronomy came in. More specifically, radio astronomy came into use. The beginning of that period was around 1931, I think, when Karl G. Jansky was working with radio in the Bell Telephone Laboratories. He had background static and could not account for it; there were bursts of static every 24 hours, to be exact, every 23 hours 56 minutes, and he realized he was getting these radio frequencies from space, because that was the rotation of the earth Radio astronomy expanded in that we could reach farther and farther into space. It was not until 1950 that radio astronomy really advanced; in fact, the fifties became a great period for radio astronomy and for the beginning of space astronomy. We began to launch some balloons. I believe Schwarzschild sent up a balloon, in the latter part of 1950, to about 80 000 ft, to photograph the sun. The photography, at that height, was great above the atmosphere. About that time, there was also a balloon sent up to study the spectrum of Venus, and a little water vapor was detected in 1959, on Venus, with that balloon.

When Sputnik went up in 1957, a whole new era opened up in astronomy: the entire picture of astronomy changed. I say that at that time a real change was observed in the picture of the astronomer. Before that time, you pictured an astronomer as an old bearded man with his charts and his photographs, looking through a telescope, in a hemispherical dome, wondering what he would find, and as you stood there as a spectator, you would think, "Well, wonder what he will see out there?" and that sort of picture. What have we now, indeed? We still have the hemispherical dome, we have a Space Science Building and maybe a radio telescope nearby, but the astronomer today is pictured as a young astronaut, sitting on a tube, ready to fly off to the stars: so there is a great difference in the thoughts about the profession of the astronomer of these days.

The first place they thought of visiting was the moon, since it was the closest object. At last, the moon began to come into its own. In the early days of the beginning of telescopes, people were interested in the moon, but when the big telescopes came in, the moon and planets were beneath the dignity of them. The big telescopes all had to be turned to galaxies, to objects that were difficult to see through small telescopes. For a long time nobody paid any attention to the moon, so space astronomy most certainly has brought the moon back into its position.

There was also that old dream about reaching the moon; you felt that you would never attain that. Now we know that is perfectly possible. However, the astronomer most certainly has set a great foundation for the astronauts to go to the moon. Actually, a great deal was known about the moon before the astronauts went there. We knew the distance, we knew something about the dust on the surface, we knew something about the topography, and we knew the great range in temperature from about boiling when the sun was shining on the moon, to close to absolute zero when it was dark. We knew that there was no air on the moon and did not believe that there was much water, although they think now they have found evidence of some water. The astronomers had mapped the moon. In 1878, for example, there was a map showing 32 000 craters.

Thus, the astronauts knew where to go and where to land, but there was one great discovery the astronauts made. I believe, the first was Russia's Lunik III, in 1959, which orbited the moon and photographed the back side. That, most certainly, was a great contribution to astronomy; this was new knowledge about the moon. Who would have dreamed, when I started astronomy 50 years ago, I would ever see any pictures of the back side of the moon! Since the moon rotates and revolves about the earth with the same period, we always see the same face, and just never would have thought that we would see the back of the moon. In the meantime, it has been photographed many times by astronauts, and the craters on the back of it have been named. Up to the time the Russians first photographed the back of the moon, 41 percent of it had never been observed. The 59 percent known to astronomers was because the rotation was not uniform. Since the revolution followed Kepler's second law, we are permitted a look around the edges, plus the fact that its axis is tilted a little, which permits looking over the poles; when it rises we can see a little over the west edge, and when it sets, a little over the east edge. So, a total of 59 percent of the moon had been observed.

Of course, we know the moon is a great place for a rock collector. We have got all those rocks that came back, but at present it is hard to say what will be determined from the study of those rocks about the age of the moon, the evolution of the solar system, the evolution of the moon, and of the earth. I think, one of the big things this trip to the moon has done is that astronomy is not so far removed from people anymore — just the fact that people actually saw the astronauts, they felt they were up there with them through television. Then, of course, their coming back, and that splashdown right on the second, "There they come!" The fact that people could look out and see those astronauts coming home has been a great contribution getting more people more interested in astronomy and particularly in the moon.

I do not believe there is today quite as much opposition to spending the money. It used to be that the taxpayer thought the money was put on the rocket and was actually sent up to the moon, that the money was up there someplace and we would never get it back. If you point out how many people are involved, and the great technology that is used today preparing for these trips then I do not think the opposition is quite as much.

The planets, of course, are always alluring. There is something about those spheres that attracts attention because there is the possibility that there might be life on them, especially on Mars and Venus. Mars, of course, has always been known as the Newspaper Planet. Years ago, when people learned that I was studying astronomy, or that I was an astronomer, they always asked, "What about life on Mars?" That was always the first question, never about life anywhere else — just what about life on Mars. I think that dates back to 1877, when there was one of the favorable oppositions. Every 2 years, Mars lines up with the Earth and the Sun; this is called an opposition. There was one in the summer of 1971, but some of those oppositions are better than others. If you get the perihelion of Mars, that is, when it is closest to the Sun, nearer the time that you have the aphelion of the Earth, we get the very closest approach. The one in the summer of 1971 was a very close one. In 1877, there was one also, and as a consequence there were great preparations in those days for the study of Mars' canali. Schiaparelli, in Italy, observed the canali; he meant to say channels (in Italian, canali means channels). The word was taken to mean artificial waterways and, therefore, there must be smart Martians who were able to make an elaborate irrigation system. You see, Mars has two polar caps, and for a long time they were believed to be ice and snow; now, they are thought to be carbon dioxide, but the proponents of the canal theory would say, when the polar cap is turned toward the Sun in summer it would diminish and then the canals become stronger. During winter, when the polar cap would get larger, the canals were not so prominent, and, therefore, people interpreted the canals as a very elaborate irrigation system for the planet. To have such an elaborate irrigation system, there had to be intelligent Martians. That, of course, attracted attention.

Then there was the excitement about the Mars satellites. The two satellites of Mars were discovered, in 1877, by an American astronomer, Asaph Hall, Sr., of the Naval Observatory. That telescope had just been completed. You could almost interpret those two satellites as artificial satellites sent up by Martians because of the timing of their revolutions. Mars rotates in 24 hours 37 minutes 22.58 seconds; the markings are very prominent, and it has been timed so many times. One of the satellites revolves around Mars in 7 hours 40 minutes, that is, it goes around three times while Mars rotates once — almost like an artifical satellite. The other one goes around in 30 hours 18 minutes, which is just a little over a Martian day — just like we observe our artificial satellites today. This caused people to speculate that they might have been artificial satellites sent up by Martians. A third satellite has now been discovered, which has a period of about 12 hours, right in between those other two. The canals on Mars and these two satellites, of course, have attracted a great deal of attention; thus, people have always been very interested in Mars, about whether or not there might be people living there.

Ground-based astronomy has detected carbon dioxide in the spectrum and some trace of oxygen and water vapor. Mariner IV photographed Mars from 6000 miles (that is as close as it came to the planet). The photographs revealed craters just like those on the moon. I do not think that has ever been suspected before, that Mars has craters similar to the Moon. The craters probably happen to line up, and it is these lines that people have interpreted as canals.

Venus, of course, is another planet that is close by the Earth. In fact, Venus comes closer to Earth than Mars. Venus, when it is the closest, is about 26 million miles distant; Mars is about 35 million miles. When Venus is closest the dark part is turned toward the Earth, therefore, up to the time of space astronomy, you never heard much about Venus because you could not see it. When Mars is closest, the illuminated part is turned toward the Earth. Venus, of course, is an object of study, especially its atmosphere. Carbon dioxide has been discovered, as well as hydrogen fluoride, hydrogen chloride, and others. For years I taught that Venus was most like Earth, and that if there was any life anywhere it would be on Venus. But the radio telescope, the radio astronomers, and also some spacecraft agree fairly well that the temperature on Venus is 800 to 900° F. If that is the case, then the Venusians cannot be like the Earthlings. We could not stand a temperature as high as that.

What about the sun? There are so many problems about the sun for which we need ground-based astronomy, balloons and orbiting solar observatories, plus everything you can think of. The sun does not rotate as a solid, for example. It rotates faster at the equator than at higher latitudes. There is a sunspot cycle, storms on the sun that have a cycle of an average 11 years, and have very far-reaching effects here on the earth. So the study of the sun with both ground-based and spacecraft observatories is very important.

As we go on out to greater distances, it is impossible to think that we will ever have a manned spacecraft or an unmanned spacecraft out to any of the stars, but we, most certainly, can have these orbital observatories. I think there are plans now for a big telescope in 1978, of 120 in. which will show stars 100 times plainer than here on earth. Now, that will change our knowledge in astronomy! It is estimated that with a 200-in. telescope on earth we could see 2 billion light-years out in space; with this new telescope, if it ever gets finished, our range would be 20 billion light-years, and then all these quasars would not be such a mystery. The quasars were first discovered by radio telescope and then, a quasar was picked up as an optical speck by ground-based telescope. Also, the spectral study showed the great red shift, the velocity of regression, that the great galaxies show.

The history of the human race is a continuous struggle from darkness toward light. It serves us, therefore, no purpose to discuss the use of knowledge. Man wants to know and when he ceases to do so, he is no longer man. In man's brief history, the challenge of cosmic space stands unparalleled. Space exploration is here whether the people like it or not, we just cannot get away from it. We have just got to keep on. I want to conclude with this statement: It does not make any difference whether we are talking about the astronomer who had the gnomon — the vertical stick — or the astronomer who will work with the big 120-in. telescope that orbits the earth. If he is a true astronomer he loves the stars too much to be fearful of the night.

Transcribed from tape.

# SESSION III

# BENEFITS OF ORBITAL SURVEYS AND SPACE TECHNOLOGY TO ENVIRONMENTAL PROTECTION

# APPLICATION OF REMOTE SENSING TO SOLUTION OF ECOLOGICAL PROBLEMS

By Andrew Adelman
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## General

When a region of the world is still virgin, such as the U.S. was 400 years ago, people are few, the land is vast, and the resources are large. We enter an era known as the era of exploration free of ecological problems. As time goes on, population grows, but resources remain constant. We find that the human groups attempt to exploit the resources of the region, agriculture resources, mining, rivers, etc., to the maximum. This we call the era of exploitation, which began for the U.S. in the early 19th century. As these resources are increasingly exploited, and as the population continues to grow, we begin to notice a phenomenon of coupling between human activities, well known in physical systems. One can consider a human enterprise as occupying a certain span of resources, such as water, land, air, and exploiting these resources to a certain degree of intensity. The problem arises when there is overlap between the various resources' span-intensity domains. It is the areas of overlap which causes the ecological problem.

Experience shows that the effects of coupling between diverse human endeavors are by and large deleterious. Is this necessarily so, or is it caused by our ignorance of the underlying mechanisms? Can the technology which has caused the problem also show the way to the cure? The answer is, very probably, yes. Theoretical and applied research and measurement systems of all types are already being focused upon the problem. Among these, the techniques of remote sensing of the environment promise significant contributions.

The significant economic consequences appear to be that increasing portions of the gross national product (GNP) will be devoted to evading the ill effects of coupling. Unfortunately, these particular portions of GNP are nonproductive. A $100 000 $SO_2$ filter in an electric coal-burning plant produces nothing in return except cleaner air. To be productive in the conventional sense, the $100 000 should be spent in more furnaces or in improving the efficiency of the process.

In addition, a growing network of management superstructure will unavoidably increase buildup Net results of inspections, studies, permits, restrictions and data gathering will be the production of the same number of automobiles, kilowatt-hours, or pairs of shoes, and will require more expenditure of time, effort, and capital, than was required during the earlier Era of Exploitation.

As a consequence, the economic standard of living will be reduced. Whether such reduction will be manifested through increased prices, more taxation, or inflation, is immaterial. The fundamental point is that more effort will have to be expended to produce the same quantity of goods as in the past. The overall net effect is to reduce the measured GNP to the lesser real GNP. Yet, if careful management of the coupling problem were not to be undertaken soon, a rather catastrophic reduction in GNP may well occur.

The era of ecology, which affects the developed nations first, may well place a natural brake upon their real expansion; whereas the developing nations, as yet free from such a brake, can continue to grow along the policies of the Era of Exploitation and, thus, catch up more rapidly with the developed nations until such time as continued exploitation eventually will also lead them into the era of ecology. This reverse lag may well become a powerful force for closing the economic gap between developed and developing nations.

The overall problem of environmental ecological management consists of three phases: (1) the establishment of the goals—namely, the determination of how much to reduce the impact on the environment, and at what burden to the different interested parties; (2) determination of who shares the costs —

not only the obvious economic costs, but also the costs in terms of limitation of other human costs; and (3) the solution of the technical problem.

We have a good grip upon the technical problem and are making progress toward reasonable solutions of equitable cost sharing. We still have problems in properly establishing the planning goals, because in large part to the lack of a theory of collective human wants. One could, however, speculate that the efforts of the next few decades may well usher in an era of deep insight into collective desires. Hopefully, such social self-knowledge can bring major, worldwide changes for the better.

It is clear now that there are two fundamental differences between the discovery and exploitation of natural resources, and their ecological management. In the former, economic return is the paramount criterion. In the later, economic payoffs vie with other, less tangible criteria as measures of success. Sometimes economic returns are of lesser priority than, for example, aesthetic motivations. In the former, the discovery and location of resources is of paramount importance. In the latter, we are much more concerned with resource exploitation and conservation dynamics as a function of time.

## Hydrological Models - Objectives

Water resources represent a major environmental problem. The current consumption of water is 6 tons per capita per day in the U.S.; less, but still quite high, elsewhere. The reason why we need so much water in industrial countries is that industrial products need many tons of water per ton of product. This would still not be too bad if the industries were to limit themselves to use of the water and return it clean. When they pollute it, the additional quantity of water required as a solvent increases the tons of water required anywhere from 7 to perhaps 20 times.

How much water is available? Because of economic reasons, only the water that falls from the sky by precipitation, which is on the average of 850 mm per year, is available. If one multiplies 850 mm times the total dry area of the earth (125 million square kilometers), one gets so many cubic meters of water. Of that, an average of 0.75 evaporates before it is utilized, so that the theoretical efficiency is approximately 25 percent although not all of that 25 percent is used. As a gross figure for the U.S., the coefficient of utilization of rainwater is only about 7.5 percent.

Extrapolating the growth of water demands to the year 2000 and multiplying by the earth's estimated population — approximately 6 to 7 billion — one computes a total demand. If this were matched to the total availability of precipitation water, and a global efficiency of utilization of 4 percent in A.D. 2000 was assumed, it is easy to determine that we will not have enough water. The available water will have to be recirculated on the average every 2000 hours; in highly developed regions, approximately every 500 hours.

There is a lot of work going on to find sources of water. Of the world's water, 97 percent is saline. Of the remaining 3 percent water, approximately 95 percent is locked in ice, mostly in polar caps. The best price today at which large quantities of water can be desalinated practically is approximately $1 per 1000 gal. The price at which a city is willing to buy is perhaps half of this. The price for agricultural water is 5 cents per 1000 gal, and the price for industrial water ranges from 10 to 20 cents. The question of desalinization is a very interesting one. It is difficult to predict when practical installations will become economical.

Studies to determine the economics of transporting Arctic ice via supertankers found that the transportation rates are too high; it cannot, as yet, be done economically. Since much of the remaining 0.15 percent of the world's stored water is located deep below the surface, the cost of drilling and of the electricity to pump is still beyond the price levels mentioned before. Therefore, at the moment, and until a technological breakthrough is effected, we are confined to utilizing only the rainwater, also known as surface fresh water, which is about 0.1000 of 1 percent of the total water available on earth. At least for the near future, the question is what can be done to utilize it more efficiently?

The problem boils down to watershed management. The watershed is a system in which the input (rainfall) is stochastic, but the output requirements are deterministic. The watershed has to provide consumers with power, based upon certain schedules. Municipalities with water, also against schedules, have to supply irrigation water, and perhaps even recreation water. The consumption schedules are relatively fixed, but the input is stochastic. The problem is how to match the two?

To do this, the Environmental Science Services Administration (ESSA) is helping to solve this problem by the development of a model to predict how much water will be available in a watershed as a function of rainfall. This model is considered the best available in practice. Let us see briefly how it works, and what improvements can be added via remote sensing.

The ESSA model does three things. First it tries to correlate how much rain falls with how much water will flow out of the watershed — that is the utilization coefficient, which is roughly 25 percent on the average but which varies with season and region. The second thing it tries to predict is the time behavior of the flow. If all the water falls very rapidly, there will be a high crest and, therefore, floods. If it comes slowly then we have a smoother curve and no floods. The flow time behavior is called a hydrograph. The third thing the model does is to combine the first two parts in the channel flow to give the overall prediction. ESSA has built 11 modifications of this basic model, which run on IBM 1130 computers for 11 watersheds.

The first piece of the model, "correlation between rainfall and runoff," is based upon four inputs. The first input is the quantity of rain that comes down at any given time. The duration of the rainfall is the second input. The third one is the season of the year. The assumption is that history will roughly repeat itself (not always true, of course). The fourth input is related to the humidity; i.e., dry soil absorbs water faster and therefore yields less runoff from a given rain, whereas wet soil tends to become impermeable and, therefore, a given amount of rain yields more runoff. It is not possible to actually go into the field and measure how wet it is; it takes too many people and too much money. The model computes something called the Antecedent Precipitation Index which is based upon the rainfall of the preceding several weeks. With this Index, the model roughly calculates the soil humidity.

The gathering of these data requires costly instrumentation. As of a few years ago, ESSA had an agreement, whereby for $3 a season, farmers would phone in some of this information. This gives an idea of what are the real-world constraints upon the system.

The second piece of the model is the construction of the time-flow curve, the hydrograph. After painstaking, laborious, and lengthy measurements, one constructs the so-called Unit Hydrograph, which is the ideal response of the watershed system to a runoff of 1 in., assumed constant over the whole watershed area. Once this Unit Hydrograph is available, then by well-known mathematical techniques, one can multiply this, by convolution, by the actual time and duration of rainfall and obtain the flow-time output. This assumes, of course, that the watershed's parameters are linear and invariant.

These are collected by three basic types of tools. The river gage measures the height of the river. The more simple ones are just sticks with numbers painted upon them, which a field worker reads periodically. At least in the U.S. and Europe, field workers are fairly expensive: $2.00 to $3.50 an hour, plus 8 cents per mile for their car, plus supplies. Thus the manual method is becoming rather expensive to use.

In addition, one would like to make this measurement frequently, at least once a day or more often during river activity periods. The trend is, therefore, to install automatic stations. Many use analog reporting, in which they write continuously on a strip of paper. The field worker now can come every 10 days or so, tear the paper chart off, and bring it back to the central data-collection facility for analysis. These towers vary from about 8 ft to 15 ft in height; some can even be higher. The cost of such an instrumentation unit can be as large as $30 000. Several are needed in a river, depending upon its length, uniformity and other characteristics.

The second tool is the rain gage. The manual version costs about $300. The field workers have the problem of reading, as was discussed before. The trend is to automate the gages by attaching them to telephone lines or providing them with radio transmitters.

The third tool measures the speed of the water. To compute the flow, one has to measure the area of the channel, or river, find the average velocity, and multiply the two. Because it is a channel flow, the speed is not the same throughout all sections; at the bottom it is low, it grows as we near the surface, then it slows down at the surface. The speed is measured at different points at various sections of the river. The measurements are then correlated and an average speed is calculated. Of course, if the river changes, this has to be done all over again. The cost, labor, and time consumption which these instruments entail call for improved systems of data collection.

How do we accomplish this? First, the ESSA model assumes the watershed to be substantially a "black box." It does not care what is inside the box. If one understands what is inside the "black box," one can get better insight and better predictions. Second, much laboratory work has been performed in hydrology. Many empirical and theoretical results are available. The problem is to extrapolate results from laboratory to the field. The reason is: economics. It is too costly to send large amounts of people into the great outdoors to gather data and to install permanent, remote measuring instrumentation.

Remote sensing appears to hold the potential for a major step forward in cost performance. From imagery, for example, we can divide the watershed into areas of homogeneity. For parking lots which have runoff coefficients of 0.9-0.95, practically all the rain runs off. Forests can have runoff coefficients very close to zero. One could, therefore, label an area which is all forest as type one; an area which is all parking lot as type two, and so forth. For each such homogeneous area one can create a kind of micromodel whose coefficients are already fairly well known from laboratory tests, then tie them all together and come up with a prediction which can be far more refined than the simple "black box" model used today.

Three things, for example, which are ignored in the present models are easily recognizable in even the poorest aerial pictures. The first one is the phenomenon of interception. When rain falls, anywhere from 0.10-0.2 in. remains attached to the plants, depending on the type of plant. Now 0.2 in. over a 100-by-100-mile watershed — which is a very tiny one — amounts to 2 weeks' flow of the Potomac. What we have to do is to recognize how much area is covered by forest and the type of forest. If we cannot tell the type of forest from the picture, we can at least send people there to obtain samples that will enable a relative determination of the type. In a large number of cases we can tell the type from observations — not necessarily photographic observa tions, but observations of the radiant spectrum — infrared, for example. The second thing is the very important phenomenon of evapotranspiration, which i simply the sweating of the plants. This again is a function of the area coverage and of the type of plant. We can also measure this from remote sensing. The third is infiltration. Every soil has different characteristics of water absorption. In parking lots, almost all the water will run off, but in sandy soil little water will run off. Experimental methods are being studied to measure the type of soil by remote sensing. We can also measure its vegetation cover, which has been shown by Holtan and others to be connected to the absorption coefficient, because certain plants grow better or grow only in certain kinds of soil. The coefficients are not 100 percent accurate, but they are already much better than having no information at all.

Additional parameters (such as soil type, basin area, stream slope, land cover, etc.) whose knowledge, for a particular watershed, could still further improve its model. All of these parameters are eminently amenable to aerial remote sensing. They are, by the way, difficult, if not impossible, to gather from maps because many of the significant features are edited out.

The point of applying remote sensing techniques to the determination of the hydrologic regime of watersheds is twofold: the improvement in predictive accuracy of already instrumented and modeled watersheds and the determination of the hydrologic regimes of as yet unknown watersheds, with potentially significant reductions in time, labor, and cost over present methods. Such a determination is an essential prerequisite for the planning of flood control and water resource utilization works within the watershed.

# APPLICATIONS OF REMOTE SENSING TO STREAM DISCHARGE PREDICTION

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## Abstract

A feasibility study has been initiated on the use of remote earth observations for augmenting stream discharge prediction for the design and/or operation of major reservoir systems, pumping systems and irrigation systems. The near-term objectives are the interpolation of sparsely instrumented precipitation surveillance networks and the direct measurement of water loss by evaporation. The first steps of the study covered a survey of existing reservoir systems, stream discharge prediction methods, gage networks and the development of a self-adaptive variation of the Kentucky Watershed model, SNOPSET, that includes snowmelt. As a result of these studies, a special three channel scanner is being built for a small aircraft, which should provide snow, temperature and water vapor maps for the spatial and temporal interpolation of stream gages. The reservoir system of the Western Division of the Bureau of Reclamation was chosen for future demonstration of how such remote observations might augment stream discharge estimates.

## Acknowledgments

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## Introduction

Remote earth observations from aircraft are being utilized to study the feasibility of applying future space payloads to stream discharge predictions. Such predictions would help in breaking the cycles between floods and droughts by distributing water more uniformly throughout the year. The more uniform distribution will preserve fertile lands and improve the production of food and fiber. The associated management of agricultural and forest resources follows directly from the water resources management.

Damaging floods in the Mississippi and Tennessee River basins were frequent before the development of water resource management systems by the Corps of Engineers and the Tennessee Valley Authority. Similar systems are now needed for other major river systems in underdeveloped countries. The Department of Civil Engineering at Colorado State University has worked on such development projects for several years with the governments of East Pakistan, West Pakistan, India, Thailand, and Venezuela.

The following paper describes the first steps of a feasibility demonstration project. The long-range objective of this project is to integrate statistical methods for machine interpretation of earth observations with hydrological simulation models for predicting the stream discharge of large drainage basins for the design and operation of major reservoir systems, pumping systems, and irrigation systems.

The short-term objective is to utilize multispectral observations of the Colorado River basin that will be obtained with MSFC instrumented aircraft for the following two applications:

1. The interpolation of sparsely instrumented precipitation surveillance networks with remote surveys

2. The direct measurement of the water loss by evaporation.

## Hydrological Models

Throughout the history of science the development of improved measurement techniques has stimulated the improvement of theoretical models of our physical environment. That is the situation with respect to remote sensing at this time. One very important area in which improved measurement techniques is stimulating the development of new models is that of water resources. Modern water resources management is based on hydrological simulation models. These fall into two categories: the first is statistical hydrology while the second consists of parametric hydrological simulation models. Statistical hydrological models may be used where many years of records are available but may not be readily extended to regions where historical records are not available.

Parametric simulation models may be used in regions where recorded streamflow data are not available and may be used to assess the effects of changes in watersheds as well as to extend records in regions where streamflow or precipitation records are inadequate.

Stanford University has developed one parametric model which is sufficiently general for applications to a great many different regions [1]. This model is illustrated in Figure 1. It may be described as a set of transfer functions which relate precipitation gage readings to stream gage readings. The precipitation gage readings are usually supplied from a measurement network within a drainage boundary. The standard format of the Bureau of Reclamation calls for hourly or daily readings of precipitation. These readings refer to the height of water or snow depth. During or shortly after rainfall or snowfall, the precipitation readings will give the direct input of available water. Measurements of evaporation from pans filled with water are used to indirectly estimate the water loss from wet soils and snow and by transpiration from plants. This loss is inferred by accounting for the changes of the measured evaporation due to soil materials, surface slopes and vegetation cover. In most drainage basins such actual evaporation losses exceed the stream discharge.

A successful hydrological simulation model should provide a reasonable agreement between the stream discharge that is predicted from the precipitation readings and the actual discharge readings of the stream gages. Such success has been achieved only for small and well instrumented drainage basins The runoff prediction of larger watersheds is difficult for two basic reasons. The first is the inadequate coverage of larger watersheds with precipitation gages. A successful simulation model requires a precipitation surveillance network which covers various infiltration conditions (interflow), slopes, and vegetation covers. The second reason is the uncertainty in the accurate prediction of evapotranspiration losses from indirect measurements.

Hydrological simulation models are needed to improve the operation of existing water resource management systems in large drainage basins and to design future reservoirs, irrigation systems, and cloud seeding operations for the more even distribution of water throughout the year. The need to improve the prediction of stream discharge for existing systems in the U.S. may be illustrated for the integrated water supply and utilization system of the Western Division System of the U.S. Bureau of Reclamation, which operates 22 reservoirs, 16 power plants, and 3 pumping stations (Fig. 2). Because of an inadequate precipitation network in an isolated region, the predictions of the Sweet Water River discharge, which originates in the Wind River Range, were off by 800 percent in 1969. This prediction would have led to extensive flood damage in Casper, Wyoming, if the reservoirs above Casper had been filled close to capacity early in the snowmelt season.

In mountainous regions, such as Colorado and Wyoming, the primary input for streamflow is winter precipitation and snowmelt. The detailed processes which produce streamflow from snowmelt are not well understood at this time [2]. However, many past investigations [3 through 10] have indicated that every watershed has characteristic relationships between snowpack depletion and streamflow runoff. Relatively simple relationships can be derived and incorporated into a model that may be used to synthesize streamflow in any given basin.

The Stanford Watershed Model [1] has been used for this purpose, but it is necessary to obtain the parameters through a trial-and-error adjustment procedure. This is not satisfactory since such a subjective approach makes extrapolation to undeveloped regions difficult. The model parameters obtained in this manner will be different depending upon the individual investigator and his understanding of the various phases of the hydrological sequence. This problem can be corrected by the use of a self-calibrating model which adjusts the parameters based upon a quantitative figure of merit.

A self-calibrating model called OPSET (Optimal Set of Parameters) [11] has been developed from an extension [12] of the Stanford Watershed Model. However, this extension does not allow for snowmelt [13], which is the primary input for streamflow runoff in the mountainous regions of interest. Another attempt at developing a self-calibrating watershed model was made at the University of London in 1970 [14]. This was also based on the Stanford Watershed Model and a numerical optimization technique developed by Rosenbrock [15]. The Rosenbrock technique was applied to the Kentucky Watershed Model by Colorado State University investigators but it was found to be entirely too consuming of computer time (Control Data Corporation 6400 computer) and consequently a gradient procedure was developed and incorporated into the Kentucky Watershed Model. This self-calibrating model includes snowmelt and has been designated as SNOPSET. The first results of this model are given here (pp. 112-113) and provide the basis for the approach toward utilization of remote observations.

## The Existing Surveillance Network

The feasibility of discharge prediction in undeveloped regions might be demonstrated by expanding self-calibrating hydrological models from well to less well instrumented watersheds. The reservoir system of the Bureau of Reclamation provides such an opportunity as shown in Figure 2. Most of the region has only very few precipitation and streamflow gages, which have, however, been recorded for many decades. These few gages support the present use of statistical hydrological models for the operational discharge forecast. However, the Bureau has now a pilot program of increasing the winter snowpack (Project Skywater) by cloud seeding by at least 30 percent. If initiated, such change of precipitation patterns might decrease the validity of the present statistical forecast, and parametric models of the SNOPSET type might thus be considered.

A new precipitation and streamflow gage network is presently being installed by Western Scientific Instruments from Ft. Collins, Colorado, in the southern test region that is shown in Figures 3 and 4. This network is designed for testing the runoff and environmental effect of cloud-seeding operations. It also provides the ideal starting area for the expansion of SNOPSET from well to less well instrumented regions. Within this newly instrumented area also exist some old gages (see Fig. 3). The large ratio of planned versus existing gages clearly illustrates the large instrumentation requirement that would exist if parametric models were to replace the present statistical discharge prediction models.

The Skywater test site consists of a number of small drainage basins. One of these, the Wolf Creek Drainage Basin, was chosen as the initial starting point for the test of SNOPSET. This basin is shown in Figure 4. It varies in elevation from about 8700 ft to slightly more than 12 000 ft. It receives approximately 600 in. of precipitation annually, covers approximately 14.5 square miles, and is approximately 80 percent forested. It has steep slopes facing generally southeast and northwest. It is generally snow-covered from mid-October to mid-June and has past records of stream gage and precipitation and temperature.

Many instrumentation problems exist, such as freezing of ink and storm damage. To avoid such loss in input continuity, someone must regularly service and maintain all gages. This is a severe operations problem in the high mountain areas that hold most of the snowpack. To illustrate, from all existing old gages shown in Figure 3, only the single location near the summit of Wolf Creek Pass was kept operating continuously enough to support streamflow prediction. Clearly, the cost of developing and maintaining an adequate precipitation network for parametric stream discharge prediction in the main precipitation area of Figure 2 would be high. We hope that this cost might be reduced by augmenting a much smaller number of gages with remote observations.

## Discharge Prediction Without Remote Observations

The Wolf Creek Drainage Basin has only a single location where the continuity of old precipitation readings is sufficient for parametric models. However, the use of only one precipitation gage is usually not sufficient to adjust the model parameters for a representation of the drainage basin at hand. The adjustment of SNOPSET was nonetheless attempted by augmenting precipitation with temperature records (daily maximum and minimum).

Figure 5 indicates the results from the first guess at the hydrological parameters in the model using the 1968-1969 water year as a test case. The correlation between recorded and synthesized mean daily streamflows is quite poor. Figure 6 shows the same results after 19 self-calibrating iterations of SNOPSET. The correlation in this case is very good (0.94). The associated choice of model parameters was then verified by applying the unchanged model to the 1969-1970 water year.

The results are shown in Figure 7. It is apparent that the "plant transfer function" has been adequately determined by application of SNOPSET.

The good correlation between computer and predicted stream discharge indicates that the use of parametric models might offer opportunities for reducing the density of streamflow gages. However, Figure 7 does not imply any forecast ability since model input and output overlap in time.

The predictive ability of SNOPSET was tested by extrapolating the streamflow beyond the time of the precipitation and temperature inputs. The results are shown in Figure 8. The abscissa shows the forecast period; i.e., the period between the computed discharge and the last precipitation measurement. The ordinate shows the quality of the prediction in terms of a standard deviation between the daily averages of predicted and measured streamflow. This deviation is approximately 3 times the residual deviation that remained after adjusting the SNOPSET parameters as shown in Figure 7. Apparently, the model provides a good prediction over a forecast period of approximately 6 months. This is adequate for covering the period of snowmelt. During these forecasts, the predicted and measured streamflows correlate within approximately 75 percent. For a forecast in excess of 6 months, the deviation between measurement and forecast increases more and more. We believe that the above results warrant to base a continuation of our present demonstration project and suitable updated versions of SNOPSET, that would take remote observation in addition to readings from a few precipitation and temperature gages.

## Aircraft Instrumentation for Augmentation of Precipitation Measurements

Our first demonstration on the interpolation of precipitation gage readings with remote observation will be restricted to the snowpack in high mountain areas. The area extent of snow can easily be detected from space and the depletion of the snow cover appears to be directly related to runoff characteristics [3 through 10]. Even the low resolution of the meteorological satellites gave adequate estimates of the yearly precipitation input in the Sierra Nevadas. Monthly inputs to smaller drainage areas can hopefully be derived from repetitive surveys that provide higher resoultion images, such as the Earth Resourc Technology Satellite (ERTS-A). Additional significa information for discharge prediction can hopefully be derived from incremental changes of the melt line. The boundary of melting snow should be accessible from the 0° C contour of a thermal map.

Any application of space observations to stream discharge prediction would lose most of its value if the precipitation estimate does not include rain besides snow. Unfortunately, the interpolation of rainfall gages is much more difficult than the above extrapolation of snowfall measurements since soil moisture is much more difficult to detect.

Temperature anomalies and greening of dry vegetation have been proposed as qualitative and indirect indicators of rainfall. However, then indicators may have many other causes besides recent rain and are thus probably not feasible for the interpolation of rainfall gages. We propose instead to use a map of the vertically integrated water vapor mass. Incremental changes of such a map should provide information on the water loss by evaporation and transpiration, which is also indicated by the decrease of the precipitation level in the rain gages. Repetitive surveys of the water vapor mass distribution should thus allow interpolation of rain gages shortly after precipitation inputs when these levels decline. Hopefully, this interpolation will also hold for the immediately preceding period of rainfall that was indicated by rising gage levels.

The CSU aircraft with a special scanner to provide maps of snow cover, temperature, and vertically integrated water vapor mass (Fig. 9) is being instrumented by MSFC. This scanner has three channels, two for reflected sunlight (0.83 to 0.87$\mu$m and 0.91 to 0.95$\mu$m), and one for thermal emission (8 to 12$\mu$m). The restriction to only three channels was necessary to conserve weight and funds so that a small aircraft may be used for surveying hourly and daily variations of precipitation as required by the direct surveillance network.

The bandpass of the first reflectance channel is chosen so that atmospheric propagation effects of water vapor are minimized. This channel will be used to provide the snow maps. A normalizing factor is measured directly per scan line by viewing the above sky screen. By using this additional reference pulse, channel 1 can be used to correct for extraneous illumination factors such as partial cloud cover.

The thermal channel is viewing a sky screen once per scan mirror revolution to obtain a signal that is related to the ambient temperature of the aircraft housing. In addition, the thermal channel will record the emission of an adjustable and stabilized blackbody calibration source. These two additional calibration pulses are then used to convert the thermal signal into a radiometric temperature that should provide a good approximation of the surface temperature.

The bandpass of the second reflectance channel coincides with the absorption band of water vapor at 0.93$\mu$. This channel should thus be used to map the transmission loss that is provided by the atmospheric water vapor.

This transmission must then be interpreted in terms of integrated water vapor mass (precipitable centimeters). Background for such spectroscopic interpretation is available from a 15-year informal and international cooperation on the propagation characteristics of the water vapor molecule. The results of this investigation are summarized by the Wave Propagation Laboratories of the National Oceanic and Atmospheric Administration (NOAA) [16]. Their Slant-Path computer codes have been made available to MSFC as part of a previous joint field test program.

The proposed water-vapor map would account for the total water-vapor mass between the ground and the scanner; whereas, the hydrological applications refer only to the portion that is related to the evaporation from the underlying soil and the transpiration from plants. The balance is provided by humidity in converted air masses. As long as this convection circulates the air within the large drainage area of interest, one might expect that its effect would cancel out in the integration across this area [17]. However, a significant influx of atmospheric moisture into the drainage area might present interpretation problems. In such an event, statistical correlation concepts are conceivable which might retrieve the evapotranspiration component by a digital correlation of water-vapor and temperature maps.

## Conclusion

The successful statistical prediction of stream discharge from historical records of a few gages implies that the spatial interpolation of precipitation gages does not need high local accuracy for obtaining acceptable overall precipitation inputs. Remote observations might thus have a chance for spatial interpolation of a few gages over large regions, as shown in Figure 2. The above successful forecast over 6 months also implies that the temporal interpolation between successive overflights does not need a great local accuracy. Temporal interpolation errors are obviously acceptable within the deviations of daily averages that are indicated by the statistical hydrological models in present use. A 9-day interval between remote observations of half the drainage area is within the capability of existing unmanned satellites (ERTS) and might suffice for the temporal interpolation.

A special aircraft scanner is being built and tested which should provide maps on the aerial extent of snow, on surface temperature and on the vertically integrated water vapor mass for the spatial and temporal interpolation of a few precipitation gages. Such demonstrations should be conducted in large drainage areas where statistical hydrological models are being used. The errors of the local interpolation can be spot checked in small subregions, where the existing gage network is sufficient to support the adjustment of the SNOPSET parameters for local streamflow estimates without remote observations. The errors of the local space and time interpolation would thus be established by reducing the number of gage inputs while simultaneously using remote observations. The errors of the overall precipitation inputs and evapotranspiration losses would subsequently be established by estimating the propagation and self-cancellation of the local interpolation errors in the space and time integrals that establish the overall precipitation inputs to the drainage area. The feasibility of using space observations for precipitation estimates becomes apparent by comparing the estimated overall errors with the tolerances that were established when using the statistical forecast method. If feasible, the use of space observations would then provide for adjusting the statistical methods for changes in the drainage area by cloud-seeding operations, new river channels, new reservoirs, etc. Equally, if not more important, the use of space observations might provide stream discharge forecasts in undeveloped regions, where several decades of precipitation and discharge records do not yet exist.

Evaporation losses usually exceed the water flowing in the tributaries and their accurate knowledge is thus necessary if one wants to predict discharge by subtracting precipitation and evaporation. Most parametric hydrological models estimate evaporation losses with empirical factors which account for various soils, vegetation covers, slopes, etc., in the drainage basin. Many of these factors might not be needed if the evaporation loss can be estimated from the water vapor mass. The survey of atmospheric water vapor distribution is thus not only needed for estimating overall rainfall, but may also assist in developing parametric stream discharge prediction models in sparsely instrumented drainage areas.

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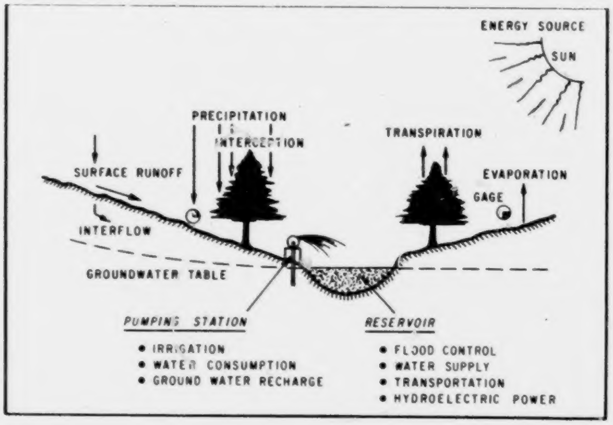

ENERGY SOURCE
SUN
PRECIPITATION
INTERCEPTION
TRANSPIRATION
SURFACE RUNOFF
EVAPORATION
GAGE
INTERFLOW
GROUNDWATER TABLE
PUMPING STATION
• IRRIGATION
• WATER CONSUMPTION
• GROUND WATER RECHARGE
RESERVOIR
• FLOOD CONTROL
• WATER SUPPLY
• TRANSPORTATION
• HYDROELECTRIC POWER

Figure 1. Hydrological applications in Colorado and Tennessee Valley.

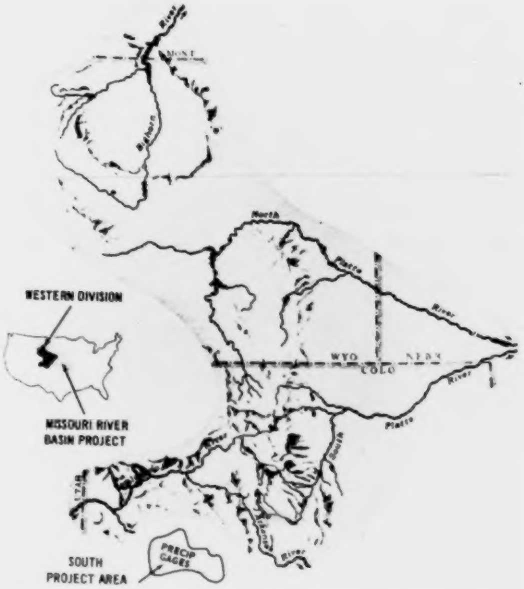

River
MONT
Bighorn
North
Platte
River
WESTERN DIVISION
MISSOURI RIVER BASIN PROJECT
WYO
NEBR
COLO
River
Platte
South
River
UTAH
River
PRECIP GAGES
SOUTH PROJECT AREA

Figure 2. Reservoir operations by Bureau of Reclamation.

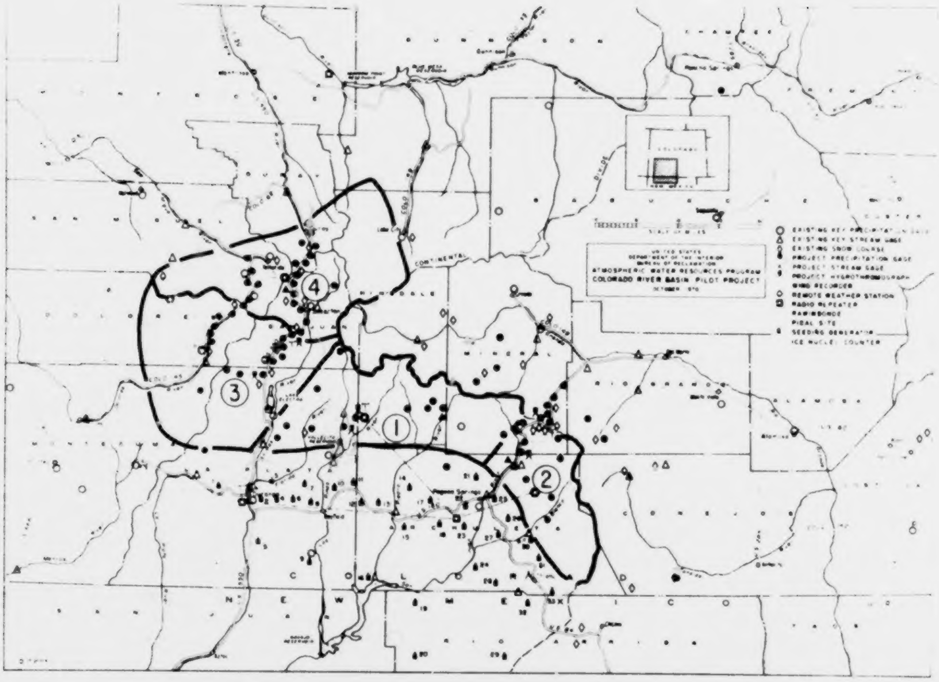

4
3
1
2
CONTINENTAL
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
ATMOSPHERIC WATER RESOURCES PROGRAM
COLORADO RIVER BASIN PILOT PROJECT
OCTOBER 1970
SCALE OF MILES
EXISTING KEY PRECIPITATION GAGE
EXISTING KEY STREAM GAGE
EXISTING SNOW COURSE
PROJECT PRECIPITATION GAGE
PROJECT STREAM GAGE
PROJECT HYGROTHERMOGRAPH
WIND RECORDER
REMOTE WEATHER STATION
RADIO REPEATER
RAWINSONDE
PIBAL SITE
SEEDING GENERATOR
ICE NUCLEI COUNTER

Figure 3. Precipitation surveillance network in the Colorado River Basin.

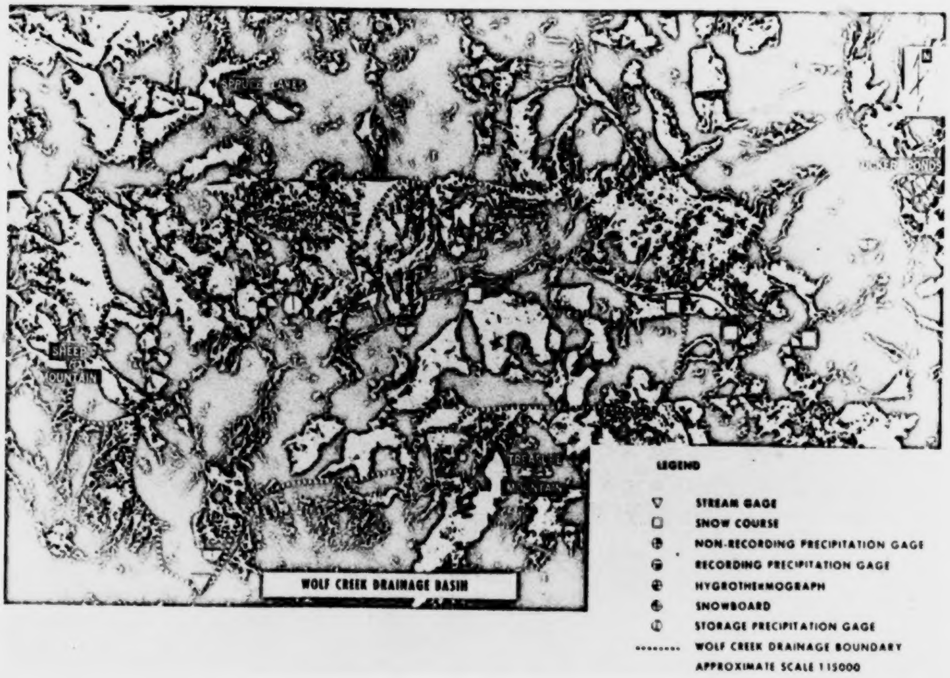

SPRUCE LAKES
TUCKER PONDS
SHEEP MOUNTAIN
TREASURE MOUNTAIN
WOLF CREEK DRAINAGE BASIN
LEGEND
STREAM GAGE
SNOW COURSE
NON-RECORDING PRECIPITATION GAGE
RECORDING PRECIPITATION GAGE
HYGROTHERMOGRAPH
SNOWBOARD
STORAGE PRECIPITATION GAGE
WOLF CREEK DRAINAGE BOUNDARY
APPROXIMATE SCALE 1:15000

Figure 4. NASA/MSFC regional application of Colorado State University aircraft surveys, December 1970.

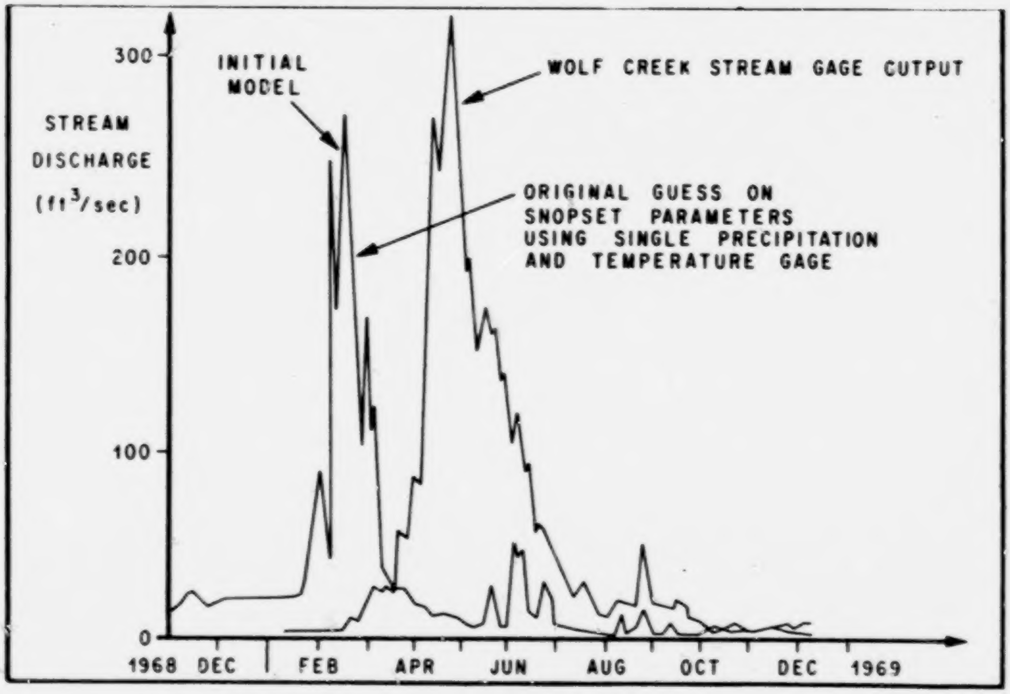


Figure 5. Calibration of hydrological model parameter for Wolf Creek Drainage Basin.

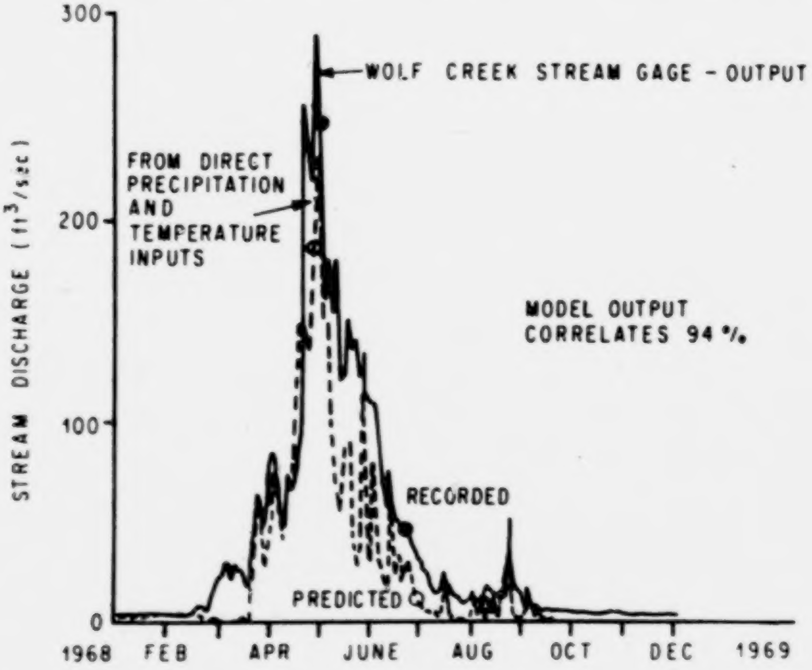


Figure 6. Records used for establishing hydrological model of Wolf Creek Drainage Basin.

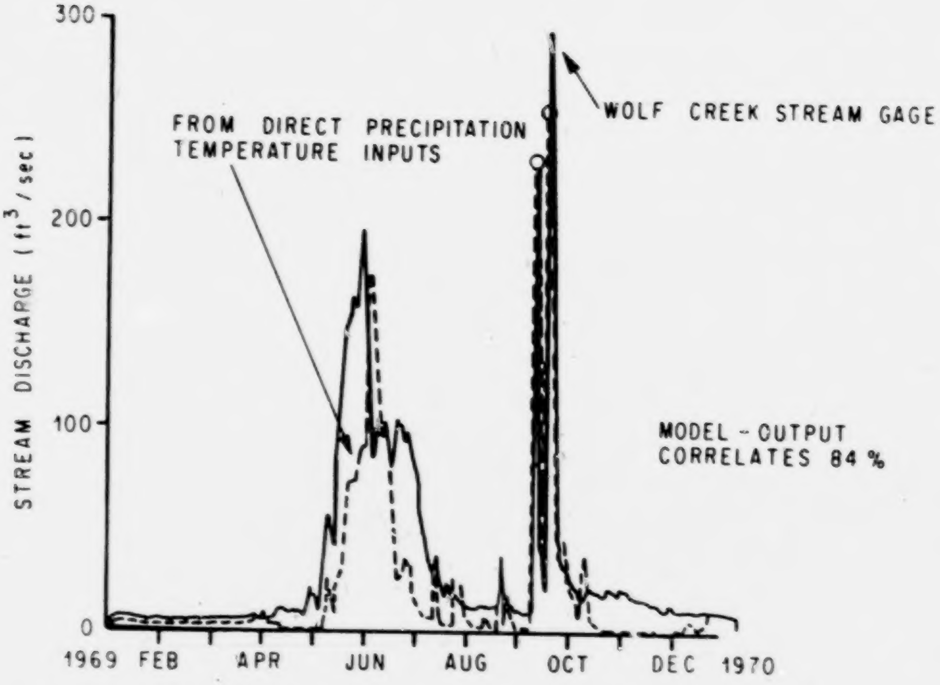


Figure 7. Verification of hydrological model through 1969-1970 stream discharge prediction.

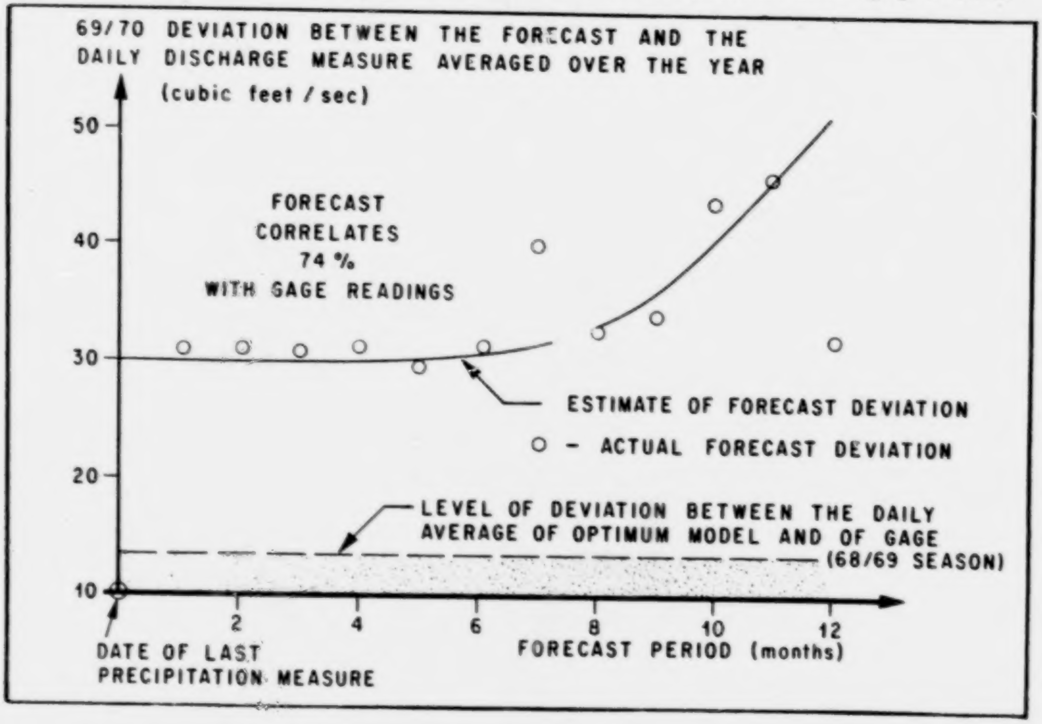
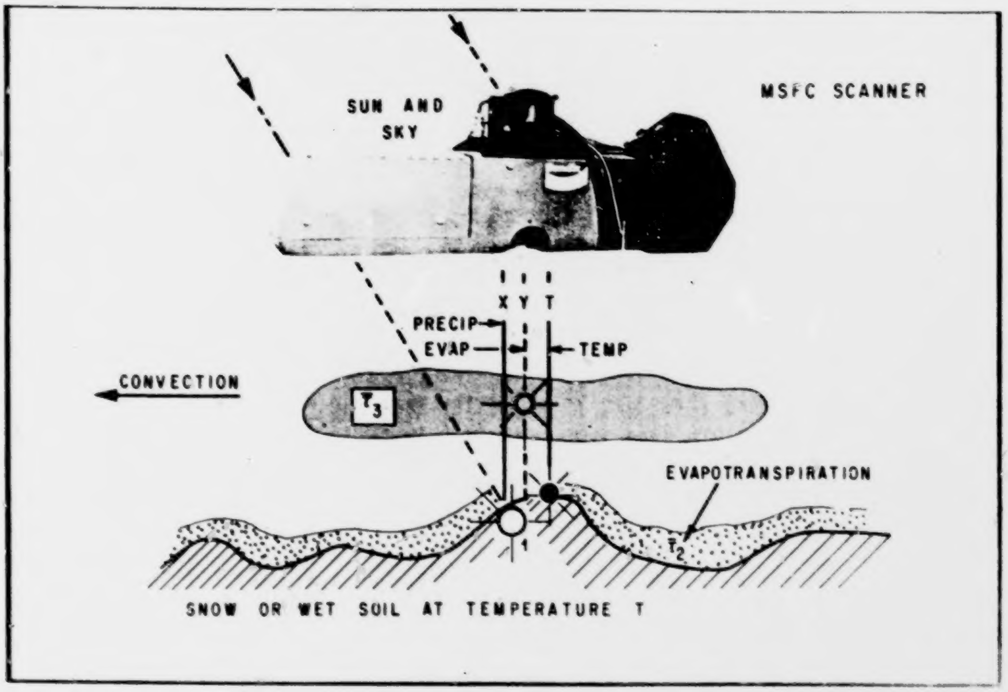


Figure 8. Streamflow prediction with self-calibrating extension at Kentucky Watershed Model.


SUN AND SKY
MSFC SCANNER
X
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CONVECTION
$\bar{T}_3$
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$\bar{T}_2$
1
SNOW OR WET SOIL AT TEMPERATURE T

Figure 9. Precipitation estimates from change of water vapor and temperature maps.

# POSSIBILITIES OF OBSERVING AIR POLLUTION FROM ORBITAL ALTITUDES

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Ontario, Canada

## Abstract

Research carried out over a number of years has indicated the feasibility of monitoring global air pollution from orbiting satellites. Data on the worldwide buildup of pollution levels on a regional scale is at present very meager. It has been established that carbon dioxide is gradually accumulating in the atmosphere and the long term possible climatic effects are some cause for concern. Far less is known about the buildup of other gases and of aerosols, and satellites could provide a most useful platform for studying trends and providing warnings of any general deterioration of the atmospheric environment.

Optical methods show considerable promise of measuring the burdens of pollution, both gaseous and particulates. Important pollution gases, such as sulfur dioxide, nitrogen dioxide, carbon monoxide, and ozone, as well as some hydrocarbon vapors, appear amenable to optical remote sensing. Satellite platforms for carrying out this work would not compete with ground monitoring stations but rather supplement them with a different type of data which could be integrated with ground level measurements to provide an all-embracing picture of pollution buildup, mass migration, and dissipation.

## Acknowledgments

The author acknowledges the support received from many agencies contributive to the development of correlation spectroscopy and interferometry including NASA, MAS, MSFC, HQ, EPA, DEMR, DRB, NRC Ottawa, USAF and U.S. Army, and finally NASA-LRC and General Electric for the COPE interferometer.

## Introduction

A growing awareness of the earth's finite capability to divest itself of the increasingly large tonnages of atmospheric pollutants, results from man's activities, has placed increased emphasis on the need for continuous monitoring of airborne contaminants on a regional and global scale.

The enormous expansion in the use of fossil fuels by the industrialized nations of the world has not only created serious problems of air quality around the centers of population, but the impact of mass transport of toxic contaminants to hitherto unspoiled regions of the world is becoming increasingly apparent. For example, in Scandinavia it is claimed that sulfur dioxide from Great Britain is contributing to the steadily increasing acidity of lakes in that region and to the decrease in lichen growth on the mountains of Norway. With the advent of remote sensing measurements from satellites or aircraft, it will be possible for the first time to establish the amount of mass transfer of sulfur dioxide across the North Sea and eliminate conjecture on this point.

Satellite and aircraft monitoring of atmospheric contaminants using remote sensors adds a new dimension to existing methods of pollution measurement. Downward-looking satellite systems will provide a measure of the total burden of specific contaminants in the earth's atmosphere and will permit considerable extension and extrapolation of ground-based data. Whereas the satellite monitor will provide global maps of pollutant distribution, it cannot alone provide absolute concentrations. On the other hand, it is simply not feasible to cover the whole earth with a comprehensive network of ground stations. Therefore, satellite monitoring will be complementary to and not competitive with ground monitoring methods.

In addition to enabling the scientist to study the circulation patterns of large air masses in the global atmosphere, the satellite sensor will aid in the investigation of interacting effects of pollution, the effective lifetimes of specific gaseous species in the atmosphere, and the long term effects of a sustained buildup of polluting materials.

Carbon monoxide, for example, is being added to the atmosphere at a rate which would cause the global background to almost double every 2 years if we take into account the various removal mechanisms or sinks now known to exist. Since this is not happening and, in fact, the available data, albeit very meager, show no apparent increase in the mean global concentration in the last 20 years, it is clear that carbon monoxide is being removed from the atmosphere by one or more mechanisms not yet fully understood.

The global mapping of carbon monoxide from a satellite offers the intriguing possibility of being able to correlate the distribution of carbon monoxide over the global surface, with geographical features and circulating air masses, in such a way as to delineate the carbon monoxide sink anomalies. It may also be possible to investigate possible modes of carbon monoxide dissipation in the upper atmosphere by orienting the satellite sensor to observe the earth's limb using the direct radiation of the sun.

There is also serious concern that the slow but relatively steady buildup of carbon dioxide (0.66 ppm per month) could have a long term warming effect on the earth's climate. Projections of this so-called greenhouse effect are complicated by the increasing burden of particulate or aerosol pollution, which could conceivably produce an effect in the opposite sense; i.e., a cooling trend in the global climate.

A relatively recent development, posing possible threats to the global ecology, is the advent of the supersonic aircraft and large rocket engines which are capable of dumping large tonnages of spent pollutants and water vapor in the upper atmosphere, where the photochemical activity is very high and the meteorological conditions of dispersion are entirely different from those prevailing in the troposphere.

With satellite remote sensing equipment of appropriate design it should be possible to monitor the behavior of these high altitude pollutants more effectively than from aircraft or ground-based observations.

## Monitoring From Orbital Altitudes

Remote sensing of atmospheric material requires a source of radiant energy, and for nadir-looking sensors, two forms of solar radiation may be received (Fig. 1). One is reflected solar radiation which bounces off the surface of the earth or its atmosphere and covers the spectral region between 3000 Å in the ultraviolet and about 4 μm in the near infrared. The other is thermal radiation emitted from the earth as a blackbody at 300° K which lies in the region between about 4 and 15 μm. Sulfur dioxide exhibits strong absorption spectra in the 3000 to 3200 A region, and nitrogen dioxide shows almost continuous but very irregular absorption features from the ultraviolet to the visible region. The infrared regions are particularly rich in absorption and emission spectra, and in fact, virtually all gaseous pollutants of interest report in the 1 to 15 μm region. The physics of the measurements of atmospheric gases is relatively straightforward in the cases of those species which absorb in the ultraviolet, visible, or near infrared but increases in complexity for those gases which exhibit absorption in the thermal regions of the infrared. In the latter case the temperature of the gas being measured becomes critical, and when high altitude measurements are being made, the effects of pressure also have to be taken into consideration. Also, in both the near and thermal infrared the region is so heavily populated with gas spectra, many of which tend to overlap, that the achievement of adequate sensor sensitivity with good interference rejection is a problem of some magnitude.

In the ultraviolet and visible regions the interference problem is much less severe; however, the spectral signatures of near-surface gases are significantly weakened by atmospheric absorption and backscatter. The resulting signal is particularly troublesome in the ultraviolet. These effects are shown diagrammatically in Figure 2.

It is possible to measure concentrations of a gas by noting the absorption obtained at one wavelength corresponding to a strong absorption band in the gas, and comparing it with the absorption at an adjacent wavelength where the gas does not absorb. This simple technique, however, tends to be subject to interferences because of the fact that absorption bands are seldom unique, and it is generally impossible to pick a pair of wavelengths which will not suffer from some differential absorption because of the presence of gases other than the one being sought.

An effective method of combating this interference problem is to correlate a substantial portion of the absorption spectrum of the gas being measured against a stored replica or mask of the spectrum. The term "correlation spectroscopy" has been coined to describe this technique. A significant number of prototype instruments have been constructed employing this principle. Over the past 5 years, various configurations of the correlation spectrometer have been extensively evaluated. In September 1969 a high altitude balloon experiment was performed to test the feasibility of monitoring atmospheric sulfur dioxide and nitrogen dioxide from above the ozonosphere.

While correlation spectroscopy is convenient to apply in the ultraviolet, visible, and near-infrared portions of the spectrum, it becomes more convenient to use interferometric methods in the middle and far infrared. Detectors are far less sensitive in this region and there is a much greater requirement for large light throughput in the detection device. This condition is satisfied by an interferometer, and by scanning the path difference in the interferometer, an interferogram can be generated which may be converted into a spectrum by means of a Fourier transform operation in a computer. In the correlation interferometer, however, the gas correlation is carried out directly in the interferometer against a stored replica of the interferogram of the gas being detected. The intermediate Fourier transform step is omitted, thereby greatly simplifying the approach. This is possible because of the fact that the Fourier transform of a gas spectrum is as unique as is the spectrum itself.

## Remote Sensing in the Ultraviolet and Visible

A remote sensing correlation spectrometer for $SO_2$, $NO_2$, and $I_2$ was developed and extensively evaluated in various airborne measurement programs. The results of these tests were so encouraging that a high altitude balloon experiment was conceived as a means of testing the feasibility of monitoring $SO_2$ and $NO_2$ concentrations in the lower atmosphere from satellite altitudes; i.e., from above the ozonosphere.

Thus, a high altitude balloon project was sponsored jointly by the NASA Manned Spacecraft Center (MSC) and the Canadian Department of Energy Mines and Resources. Chicago was selected as the ideal site because of its large population, heavy industrial activity, excellent ground-monitoring network, and its proximity to Lake Michigan as a large background area. The prime aim of this experiment was to see how large the $SO_2$ and $NO_2$ signals would be when viewed from high altitude, normally 114 000 ft. At this altitude the balloon would be above most of the ozonosphere, which is the upper atmospheric layer of ozone which acts as a powerful absorber of ultraviolet light. When using the balloon platform the signals of the polluting gases are impressed upon the reflected light from the earth's surface, the light having made two passes through the air layer. Therefore, apart from its normal alternation, the signal is diluted by atmospheric scattering.

For the balloon flight, two correlation spectrometers were flown, one measuring $SO_2$ in the ultraviolet region; the other measuring $NO_2$ in the blue visible. These two gases had two critical problems in common, Fraunhofer line interference in the solar spectrum and dilution of their spectral signatures because of atmospheric absorption and scattering. Sulfur dioxide measurements had the added disadvantage, caused by the strong absorption of the ultraviolet radiation by the ozonosphere and the greater scattering of the shorter wavelengths compared to that which takes place in the visible region where the $NO_2$ was measured. Mathematical models had been developed and computer programs had been generated to model the instrument's performance to a variety of outside interferences and to calculate the optimum mask designs for balloon spectrometers.

Thus, it was that early in September 1969 when two spectrometers were flown over Chicago at 114 000 ft. Their field of view was approximately 1 deg by 1 deg which resulted in ground resolution patch of 0.5 square mile. Because of polarization effects, the entire gondola was stabilized to prevent azimuthal rotation and thereby keep constant sun angle. This was achieved through the use of a solar tracker device.

Also incorporated was a flip mirror to alter the viewing direction of the spectrometer from a ground vertical to a 24 deg angle away from the solar side so that two tracks of data were generated for $SO_2$ and $NO_2$, respectively. The chart records generated during the flight were returned to Toronto for digitization, and the data were then reduced by a computer and plotted in various map presentations. Intermittent cloud coverage beneath the float path of the balloon caused voids in the data. Simultaneous with the balloon flight, we obtained vertical profiles from the correlation spectrometer mounted in a station wagon which traversed the same float path as the balloon as far as was possible. Also the noontime values of $SO_2$ were obtained from the automatic city-wide air monitoring network in Chicago which measured ground level concentrations. All of these data were assessed, reduced, and plotted on a digitized map of the Chicago area.

Figure 3 shows the computerized plot of the $SO_2$ spectrometer output signals. The spectrometer's output readings are shown plotted as discrete values on a baseline, which is the ground tract of the sensor's field of view when the flip mirror was in the 24 deg position. The circular but fortuitous float path of the balloon was the result of unstable wind vectors at float altitude, which is characteristic of upper level winds in late summer. The measurements are shown as discrete values rather than as a continuous analog signal because of the continuous grating scan system employed in the sensor.

Figure 4 shows similar data obtained when the viewing direction was vertically downward. The $NO_2$ data and the 24 deg case are shown in Figure 5 and in Figure 6 for the ground vertical case.

Note that in Figures 3 and 6 that, apart from voids in the data resulting from calibration intervals and intermittent cloud cover as previously mentioned, there is very substantial agreement between the balloon data and the concentrated sources of pollution in the Chicago metropolitan area.

Figure 1 shows the manually plotted three-dimensional profile of the station wagon data. The primary objective of the station wagon traverse was to obtain, as closely as possible, time and space coincident measurements of vertical burden $SO_2$ along the balloon ground track. Because of the unexpected departure of the balloon from the planned east-to-west trajectory, comparative measurements were possible only at the intersection of the station wagon and the balloon ground track near the Chicago monitoring station no. 23 (Fig. 7). The upward looking measurement was some 29 times larger than the downward-looking balloon measurement, indicating a dilution factor of 29 [1].

The value is some 2 to 3 times smaller than theoretical estimates but in view of the uncertainties involved, it is quite encouraging and represents an interesting first attempt at dilution measurements through the global atmosphere.

The results obtained during the balloon flight prove conclusively the viability of the correlation technique to monitor $SO_2$ in the ultraviolet spectral region and $NO_2$ in the blue visible by clearly demonstrating that solar reflected radiation, modifi by target gas signatures impressed at the earth's surface, can be obtained at satellite altitudes. Also it should be added, the characteristics of the signals obtained at the balloon were identical to those theoretically produced by mathematical modeling.

## Remote Sensing With Ground Chopper

As indicated earlier, whereas attenuation and scattering are most severe in the short wavelength regions of the spectrum, other problems become paramount in the infrared. In the latter case these include the thermal structure of the atmosphere, temperature and emissivity of the target gases, and temperature and emissivity of the earth's surface. The concept of the ground chopper was formulated to combat these problems. This concept is based on the assumption that the atmosphere is a homogeneous scatterer or at least only a slowly changing scatterer, thus a spatial scan through the atmosphere should give, at the most, only a slowly varying signal because of scattered radiation. Conversely, ground reflectivity changes within the instantaneous field of view of an instrument will cause a rapid modulation of that radiation which has passed completely through the atmosphere down to the ground and back to the sensor. A frequency filtering separation can then be performed to separate the low frequency ground reflection components. Furthermore, a frequency analysis of the data gives information about the spatial terrain characteristics which cause changes in the incident power, and the amplitude frequency spectrum may be written as a Fourier transform of the time-varying current in the detector.

Based upon the successful completion of mathematical modeling and system studies, an instrument design was developed and an instrument constructed. The ground chopper instrument comprised a two-channel radiometer. One channel was set to monitor strongly scattered spectral energy in the wavelength region of 3100 Å, while the other channel was set to monitor the 4400 Å component where the scattering is much less severe. The 3100 Å region corresponds to the $SO_2$ absorption spectrum, while the 4400 A corresponds to that of $NO_2$ absorption. The radiometer was equipped with a telescope and means of decreasing the field of view which thereby decreased the ground coverage resolution. The instrument was equipped with electronics to process the outputs of the phototube detectors, and provide automatic gain control to these tubes.

The ground chopper instrument that was constructed is shown in Figure 8, which shows the optical arrangement of the instrument. The wavelengths were selected by interference filters which were located at the face of the photomultiplier tubes to reduce scattered light contaminations. The instrument was flown at Yellowknife, Northwest Territory.

Our results show that even for this comparatively clean northern atmosphere the amount of scattered light received at approximately 1.5 km altitude was about 2 to 3 times greater than the directly reflected component in the 3100 A region; the amount of scattering received at 4400 Å was, of course, significantly less. The amount of ground chopping was found to be as high as 25 percent at an altitude of 150 m above the terrain surface when the field of view was reduced to a few feet on the ground. When the field of view was increased to approximately 20 ft on the ground, approximately 8 percent modulation was obtained. Frequency analysis of the ground chopper signal was performed and showed that, over the city of Yellowknife, the overall chopped signal amplitude tended to increase while the higher frequency constant decreased. It can be assumed that this is because of the nature of the terrain in Yellowknife, and that this situation would probably change for other locations (Figs. 9 through 11). The ground chopper experiment has indicated that while providing adequate high resolution employed in the foreoptics of the downward-looking telescope, a significant portion of the signal reflected from the ground surface is modulated by spatial changes in the ground albedo. Since it is a fact that the reflectance spectra of terrain materials are relatively flat in the ultraviolet, it is possible to assume that the modulated components of light at two closely adjacent wavelengths in the ultraviolet will be of identical intensity, providing that there are no gases present in the atmosphere which differentially absorb these two wavelengths. Conversely, the differential intensity of the ac components of two closely adjacent ultraviolet wavelengths, which have been reflected from the ground and modulated by fluctuations in ground albedo, can be used to measure the presence of an atmospheric gas which has a differential absorption at the two wavelengths. This is a simplified example which illustrates the aim of the ground chopper technique. In practice, the two adjacent wavelengths employed are sets of wavelengths which correspond to the sets used in the correlation techniques which have been described.

It will be appreciated that the method is, in a sense, inefficient in that it discards a considerable proportion of the light reflected from the ground. However, it has the advantage of automatically eliminating the atmospheric scattered component, which cannot be adequately eliminated by mathematical modeling techniques.

Although the method is most applicable in the ultraviolet for sulfur dioxide monitoring, it is also feasible to use it for nitrogen dioxide monitoring in the blue portion of the visible spectrum. Terrain reflectance curves are still relatively flat in this area, making the errors caused by spectral gradients small.

Therefore, the ground chopping technique appears to offer an opportunity for measuring the total burden of gas between an aircraft or spacecraft and the ground without interference caused by scattering effects in the atmosphere.

## Remote Sensing in the Infrared

Whereas atmospheric scattering and attenuation are of major importance in the ultraviolet and visible, at increasing wavelengths the ability to penetrate haze and smoke improves markedly. Over certain wavelength bands in the infrared, however, the natural atmospheric constituents — water vapor, $CO_2$, and ozone — absorb heavily, creating, to all intents and purposes, opaque regions of the spectrum (Fig. 12). Between 1 and 15 $\mu$m, roughly 50 percent of the spectrum is unusable for satellite monitoring purposes. In the remaining regions, i.e., the atmospheric windows, these materials absorb only weakly, and it is the task of the sensor design to select an atmospheric window in which the target gas has sufficiently intense spectral signature for monitoring from orbital altitudes. The most useful atmospheric windows are, approximately:

0.95 - 1.1 $\mu$m

1.2 - 1.35 $\mu$m

1.5 - 1.8 $\mu$m

2.0 - 2.5 $\mu$m

3.3 - 4.1 $\mu$m

4.5 - 5.0 $\mu$m

8.0 - 13.0 $\mu$m

Absorption spectra of several of the most important atmospheric pollutants are shown in Figure 13.

Figures 14 and 15 show, in somewhat higher resolution, spectra of six hydrocarbons which together represent almost 60 percent of the total hydrocarbon emissions of the automobile. Also ethylene, propylene, and 1, 3 butadiene (Fig. 14) constitute 46 percent of the photochemical reactivity of auto exhaust [2]. A comparison of these components with the relatively nonreactive methane, acetylene, and ethane suggests a potential for selective remote sensing of these gaseous components in polluted atmospheres, which constitute the principal smog-forming potential of photochemical smogs over urban areas.

In high resolution, many of the gases of interest exhibit fine spectral detail, which is unique to that molecular species. A good example of this is the first overtone of CO which is shown in Figures 12 and 13 at 2.3 $\mu$m in low resolution and in Figure 16 in high resolution.

This type of fine detail may be employed to separate a gas from strong interferents, as is being done for CO in the Barringer correlation interferometer used in the NASA/General Electric Carbon Monoxide Pollution Experiment (COPE) program mentioned earlier.

The choosing of a spectral region for the COPE experiment also illustrates two types of problems which occur in the infrared region.

The two strongest bands for the CO infrared spectrum are the 1-0 fundamental at 4.6 $\mu$m and the 2-0 harmonic at 2.3 $\mu$m. The 4.6 band, which is about 100 times stronger, is in the thermal region and is relatively clear of interferents, while the weaker overtone is overlapped by interferents but is in what may be called the transmission region. That is, when we consider the radiative transfer equation for the satellite observing geometry of Figure 17, namely,

$$I(\nu) = \left[ I_0 \exp - \int_0^{Z_1} \alpha \, ds'' + \int_0^{Z_1} \beta \exp - \int_{s'}^{Z_1} \alpha \, ds'' \, ds' \right] \rho$$

$$\times \exp - \int_{Z_1}^{Z} \alpha \, dx'' + \epsilon \beta_0 \exp - \int_{Z_1}^{Z} \alpha \, dx'' + \int_{Z_1}^{Z} \beta \exp - \int_{x'}^{Z} \alpha \, dx'' \, dx'$$

where $\beta$ is the blackbody function, we find that th terms which describe thermal emission from the earth and the gas are negligible at 2.3 $\mu$m, while th reflected sunshine term is unimportant at 4.6 $\mu$m. Thus, the radiation received, at 2.3 $\mu$m depends mainly on the amount of gas present and only very slightly on atmospheric temperature, though the temperature dependence of $\alpha$, while at 4.6 $\mu$m the radiation depends strongly on both the atmospheric and surface temperatures. Indeed, if $\epsilon = 1$ and the temperatures of the lowest layer of the atmosphere and of the surface are the same, then the contribution to I(4.6) from that layer is independe of $\alpha$ and the gas in this layer is "invisible" at this wavelength. If $\epsilon < 1$ (as is usual) and the earth radiance varies from point to point, then observations at 4.6 $\mu$m are possible only if the temperature distributions are known well enough to solve (1) or if the ground chopping technique is used.

The 2.3 $\mu$m region is free of thermal problems but shows strong interferences from other gases, mainly methane and water vapor, as shown on Figure 18, adapted from the Connes Planetary Atlas [3]. However, even though most of the CO lines are not easily distinguished on a conventional spectrum, such as in Figure 18, they still help to determine the number of photons received at these wavelengths and, thus, can be measured if the effects of the interferents can be accounted for. This can be done by the Barringer correlation interferometer which is being used on the COPE program.

The interferometer (described in more detail in the following section) forms the Fourier cosine transform of the received radiation. Since this is a linear operation, the transform (interferogram) contains the same information about the absorbing gases as does the spectrum but is displayed along a time rather than a frequency axis. Thus, just as the spectrum is a combination of distinctive lines, the interferogram is made up of distinctive signatures for each gas present (Fig. 19). The correlation technique depends on the fact that each point in the interferogram depends, in its own unique way, on the amounts of absorbers present. Thus, if the number of points M at which the interferogram J is measured equals or exceeds the number n absorbers present, it is possible to solve M equations for the n unknown amounts of gas present. This implies that it is possible to find a set of M numbers (a correlation of weighting function, W) such that

$$\sum_m \mathbf{J} \cdot \mathbf{W} = 0$$

if no CO is present and

$$\sum_m J \cdot W = (\text{amount of CO})$$

A breadboard model of the correlation interferometer, built under the COPE program, has demonstrated the measurement of less than 0.02 atm-cm CO in the presence of atmospheric amounts of $CH_4$ and $H_2O$. This would correspond to a change of 10 percent in the amount of CO in a round trip vertical path through an unpolluted atmosphere.

The interferogram also contains information on the amounts of methane and water present; these can be obtained from the same measurement by using a different correlation function, W.

This has also been done with the COPE breadboard, where applications of a suitable function W to the data where methane was an interferent in the CO measurement, yielded measurements of methane with better than 10 percent accuracy.

## Correlation Interferometry

Correlation interferometry, like correlation spectrometry, is based upon cross-correlation of incoming signal against a stored replica. In this instance we work with interferograms which are the Fourier transforms of the input spectra [4, 5]. A basic Michelson correlation interferometer is shown in Figure 20. The beamsplitter B provides amplitude division of the input spectra from F which suffers reflections from mirrors $M_1$ and $M_2$ to recombine at the detector D. Here C is the compensator plate added by Michelson to balance the two optical arms. By suitable selection of position of movable mirror $M_2$, the two beams can be caused to recombine at D in-phase and hence a minima occurs at B. If the compensator plate is now oscillated about its central position, a cyclic delay is introduced into the one arm, thereby unbalancing the interferometer to generate the well-known interferogram. Figure 20 shows the interferogram resulting from a single wavelength input. Figure 19 depicts the forms of various interferograms resulting from several spectral inputs, namely, a single discrete wavelength, two discrete wavelengths, and finally a series of equispaced spectral lines.

Recent progress in correlation interferometry has resulted in the development of the COPE field widened scanning Michelson correlation interferometer for General Electric's NASA-LRC COPE program. Figure 16 shows the first overtone absorption spectrum of CO in the 2.3 μm region, and Figure 21 shows its interferogram while Figure 22 shows a block diagram of the general signal processing involved. The interferogram centered on the delay region characteristic of CO is scanned by the oscillating refractor plate. The interferogram is heterodyned down to remove the high frequency interferogram carrier by mixing with a reference signal. The heterodyned signal is sampled and A to D converted for final processing within a minicomputer. At this final stage correlation functions are applied to reduce the effects of spectral interferences which, of course, show up as interferogram interferences in the delay domain of the interferometer. The process of correlation can best be visualized as the application of fixed amplitude digits cross-multiplied with the interferometer's output interferogram to normalize its output to represent zero CO gas output when no CO is present within the field of view, regardless of any interfering gases.

Theoretical modeling and atmospheric radiative transfer studies enable the weighting functions to be calculated for various model atmospheres. Subsequently, the instrument can have its in-program weights continually updated through actual field measurements to ensure no-gas output for no-gas input. In our particular COPE breadboard model, the interferogram is A to D converted and the weights held within the minicomputer as digital numbers applied to the digitized interferogram.

The advantages afforded by interferometers result from their large throughput, the spectral multiplex advantage, compact yet flexible design possibilities, and ready means for incorporation of correlative techniques for electronic processing, the latter obviating one of the major disadvantages of Fourier transform spectrometers, namely, that of transforming the Fourier output back to its original spectral form for analytical interpretation.

The COPE breadboard has the following salient features.

| | |
|---|---|
| Aperture Interferometer | 6.6 cm diameter |
| Telescope | 22.0 cm diameter |
| Spectral Pass Bands | 4240-4340 $cm^{-1}$ and<br>2000-2200 $cm^{-1}$ |
| Delay Scan Range | 2.5 to 4.0 mm |
| No. of Sample Points | 0 to 64 |
| Sample Length | 1 to 63 fringes |
| Scan Rate | 1 Hz |
| No. of Scans Accumulated | 1 to 500 |
| NEP | $1.6 \times 10^{-11}$ $W/Hz^{1/2}$ |
| Noise Equivalent Amount of CO (3 percent albedo and $\tau = 1$ sec) | 0.004 atm-cm |

## Conclusion

Problems of monitoring global air pollution from space platforms have been reviewed and experimental results presented of progress in the application of correlation techniques from the ultraviolet to the infrared. While results to date have been most encouraging, there is obviously considerable work to be done before a viable satellite air pollution monitoring system becomes a reality. Severe problems remain to be solved, particularly in the thermal infrared, but the technology is moving ahead rapidly, and there appears to be no insurmountable obstacle to the global mapping of most atmospheric pollutants from orbital altitudes.

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4. Barringer, A. R. and McNeill, J. D.: Advances in Correlation Techniques Applied to Spectroscopy. National Analysis Instrumentation Division of ISA Symposia, New Orleans, La., May 1969.

5. Dick, R. and Levy, G.: Correlation Interferometry. 1970 Aspen International Conference on Fourier Spectroscopy, AFCRL 71-0019, January 1971.

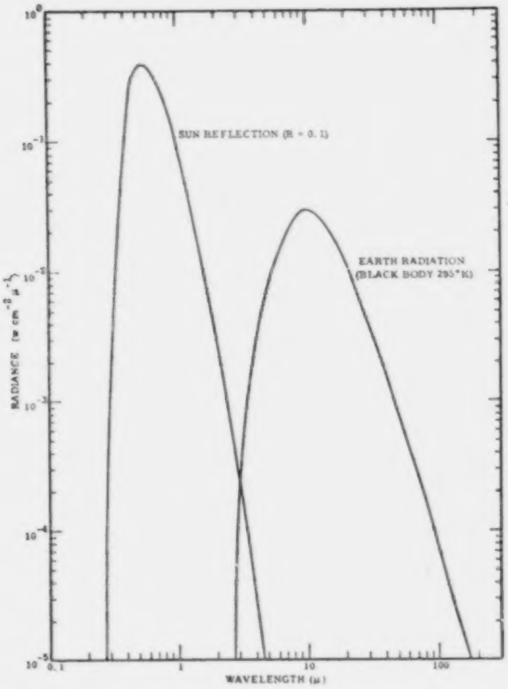

Figure 1. Contributions of the sun and earth to earth radiance.

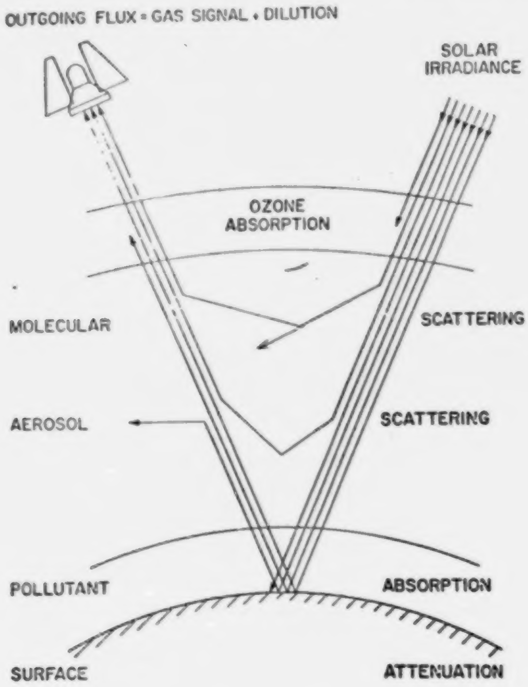
OUTGOING FLUX = GAS SIGNAL + DILUTION
SOLAR
IRRADIANCE
OZONE
ABSORPTION
MOLECULAR
SCATTERING
AEROSOL
SCATTERING
POLLUTANT
ABSORPTION
SURFACE
ATTENUATION

Figure 2. Attenuation and dilution in the ultraviolet.

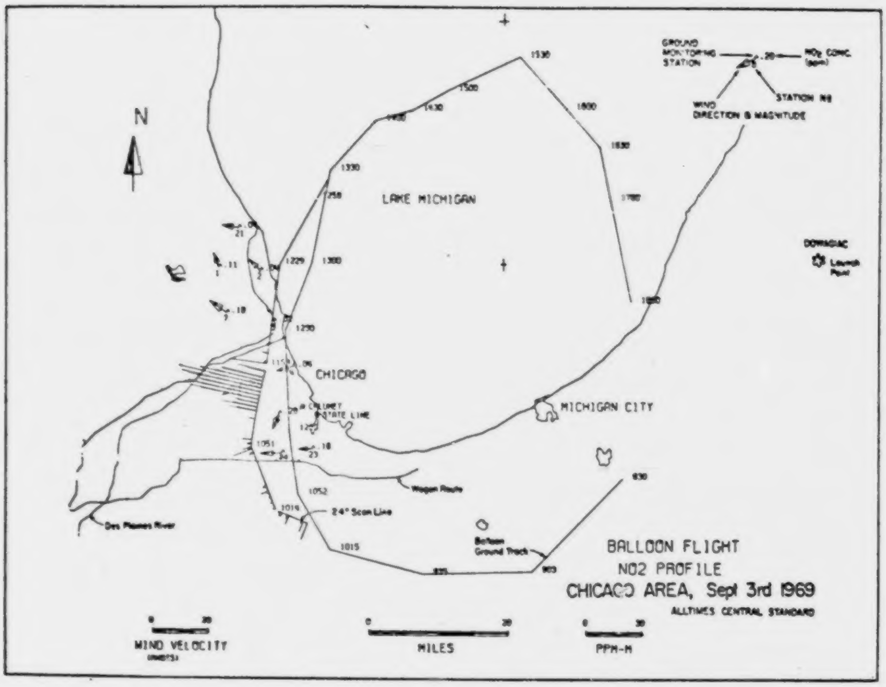
GROUND MONITORING STATION
$NO_2$ CONC. (ppm)
STATION NO
WIND DIRECTION & MAGNITUDE
N
LAKE MICHIGAN
DOWAGIAC
Launch Point
CHICAGO
CALUMET
STATE LINE
MICHIGAN CITY
Wagon Route
Des Plaines River
24° Scan Line
Balloon Ground Track
1530
1500
1430
1400
1330
1250
1229
1300
1600
1630
1700
1800
1230
1051
1052
1019
1015
935
900
830
BALLOON FLIGHT
NO2 PROFILE
CHICAGO AREA, Sept 3rd 1969
ALLTIMES CENTRAL STANDARD
0
20
WIND VELOCITY
(KNOTS)
0
20
MILES
0
30
PPM-M

Figure 3. Computerized plot of the $SO_2$ spectrometer output signals.

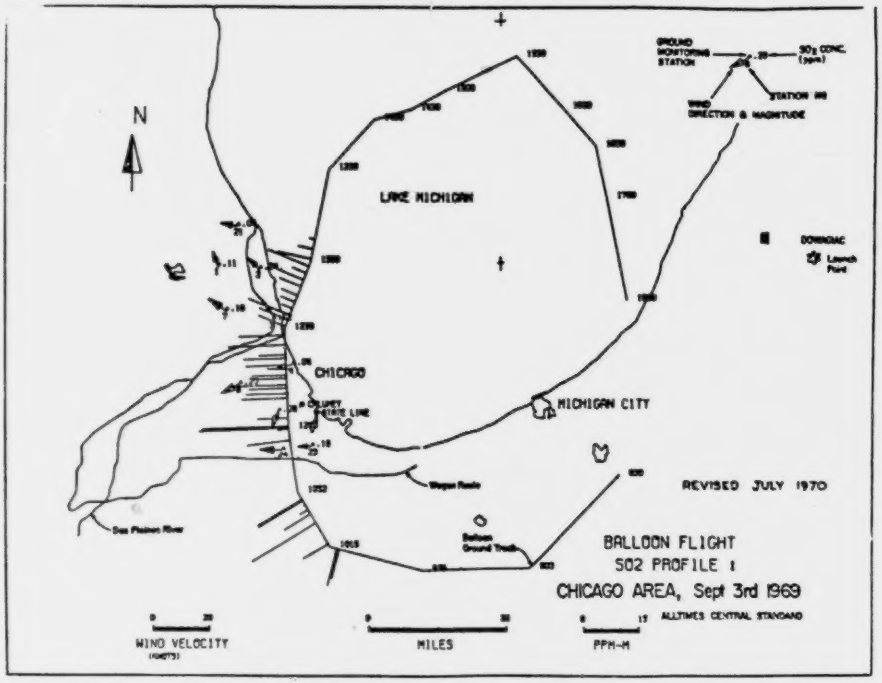
GROUND MONITORING STATION
$SO_2$ CONC. (ppm)
STATION NO
WIND DIRECTION & MAGNITUDE
N
LAKE MICHIGAN
DOWAGIAC
Launch Point
CHICAGO
CALUMET
STATE LINE
MICHIGAN CITY
Wagon Route
Des Plaines River
Balloon Ground Track
REVISED JULY 1970
BALLOON FLIGHT
SO2 PROFILE I
CHICAGO AREA, Sept 3rd 1969
ALLTIMES CENTRAL STANDARD
0
20
WIND VELOCITY
(KNOTS)
0
20
MILES
0
15
PPM-M

Figure 4. Vertical viewing direction.

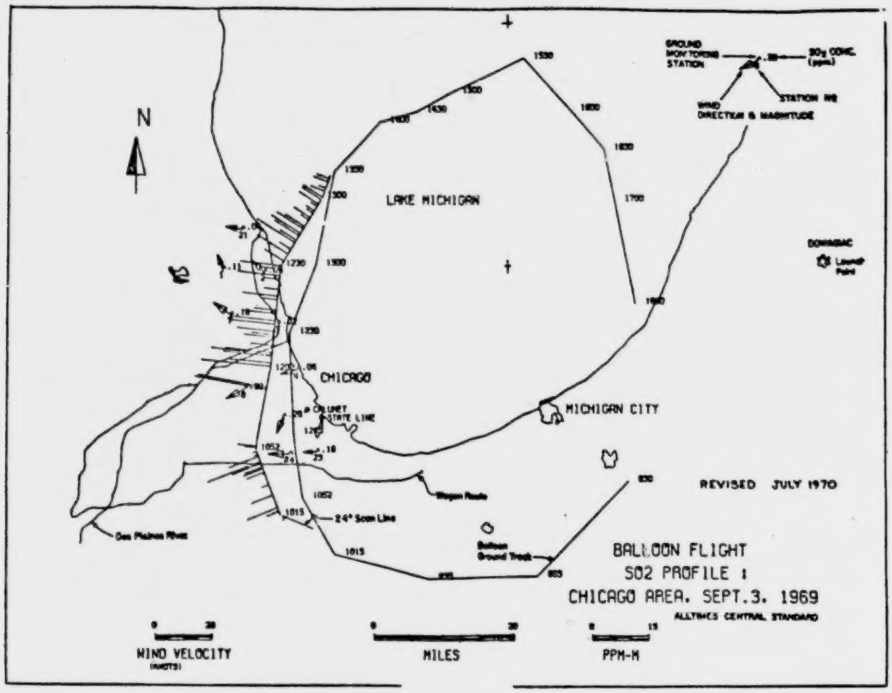
GROUND
MONITORING
STATION
$SO_2$ CONC.
(ppm)
STATION No
WIND
DIRECTION & MAGNITUDE
N
LAKE MICHIGAN
CHICAGO
CALUMET
STATE LINE
MICHIGAN CITY
DOWAGIAC
Launch
Point
Wagon Route
24° Scan Line
Des Plaines River
Balloon
Ground Track
REVISED JULY 1970
BALLOON FLIGHT
SO2 PROFILE 1
CHICAGO AREA. SEPT.3. 1969
ALLTIMES CENTRAL STANDARD
WIND VELOCITY
(KNOTS)
MILES
PPM-M
1530
1500
1430
1400
1800
1830
1700
1900
1330
1300
1230
1052
1015
930

Figure 5. $NO_2$ data for 24 deg case.

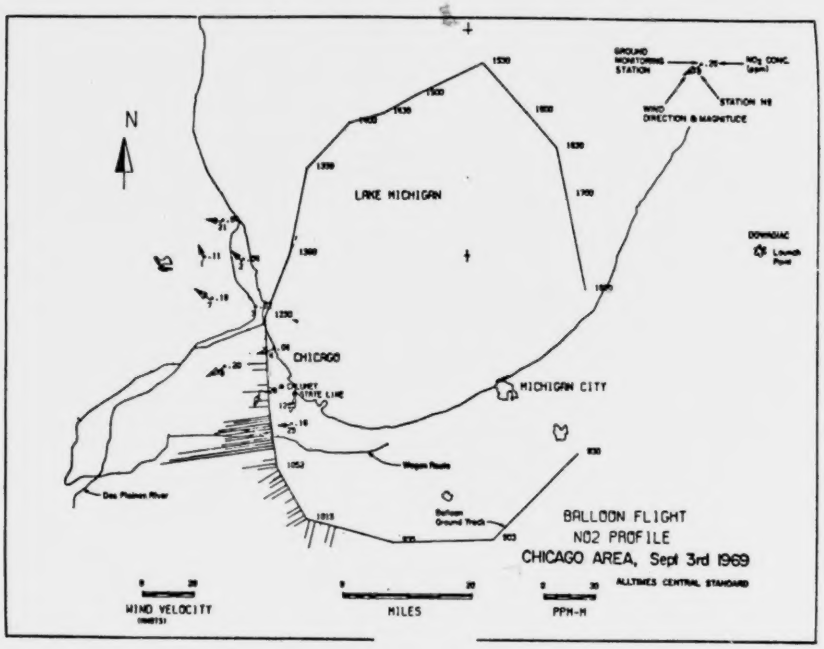
GROUND
MONITORING
STATION
$NO_2$ CONC.
(ppm)
STATION No
WIND
DIRECTION & MAGNITUDE
N
LAKE MICHIGAN
CHICAGO
CALUMET
STATE LINE
MICHIGAN CITY
DOWAGIAC
Launch
Point
Wagon Route
Des Plaines River
Balloon
Ground Track
BALLOON FLIGHT
NO2 PROFILE
CHICAGO AREA, Sept 3rd 1969
ALLTIMES CENTRAL STANDARD
WIND VELOCITY
(KNOTS)
MILES
PPM-M
1530
1500
1430
1400
1800
1830
1700
1900
1330
1300
1230
1052
1015
930

Figure 6. $NO_2$ data for ground vertical case.

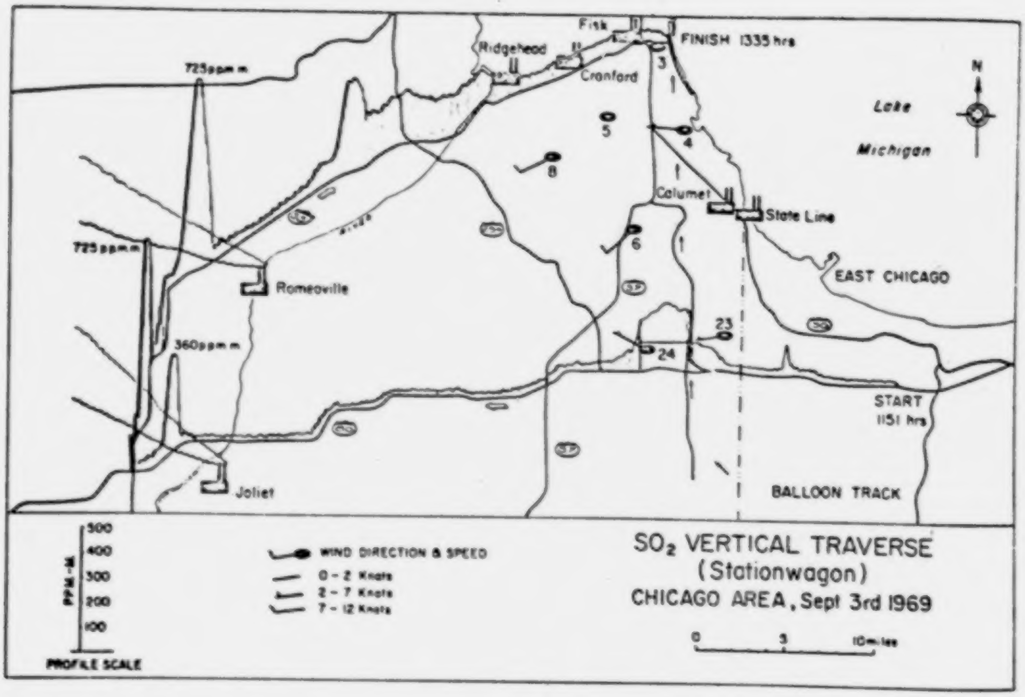
Fisk
Ridgehead
FINISH 1335 hrs
Cranford
3
725ppm m
Lake
Michigan
N
5
4
8
Calumet
State Line
6
725ppm m
Romeoville
EAST CHICAGO
23
360ppm m
24
START
1151 hrs
Joliet
BALLOON TRACK
500
400
300
200
100
PPM-M
PROFILE SCALE
WIND DIRECTION & SPEED
0 - 2 Knots
2 - 7 Knots
7 - 12 Knots
SO2 VERTICAL TRAVERSE
(Stationwagon)
CHICAGO AREA, Sept 3rd 1969
0
5
10miles

Figure 7. $SO_2$ vertical traverse.

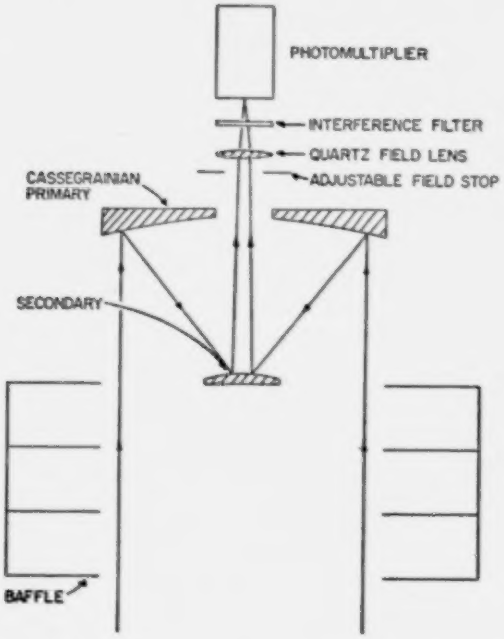
PHOTOMULTIPLIER
INTERFERENCE FILTER
QUARTZ FIELD LENS
ADJUSTABLE FIELD STOP
CASSEGRAINIAN PRIMARY
SECONDARY
BAFFLE

Figure 8. Ground chopper optics.

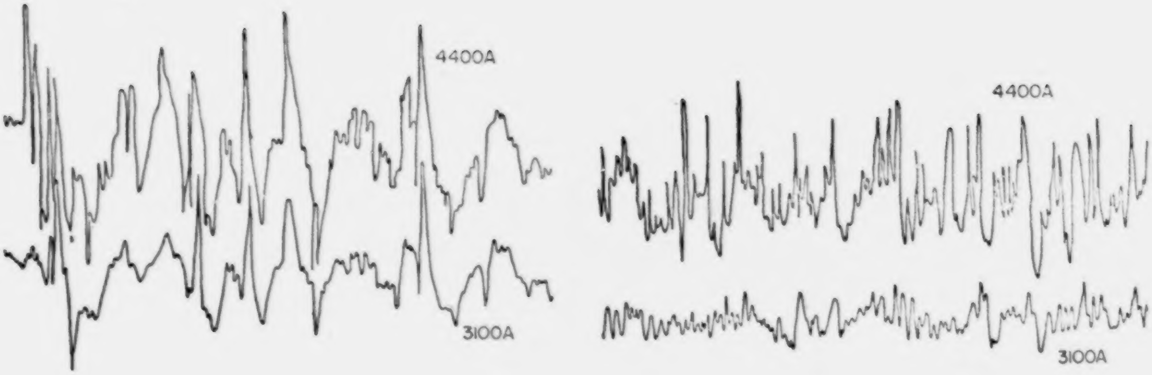

Figure 9. Ground chopped signal over Yellowknife (left) and natural terrain (right).

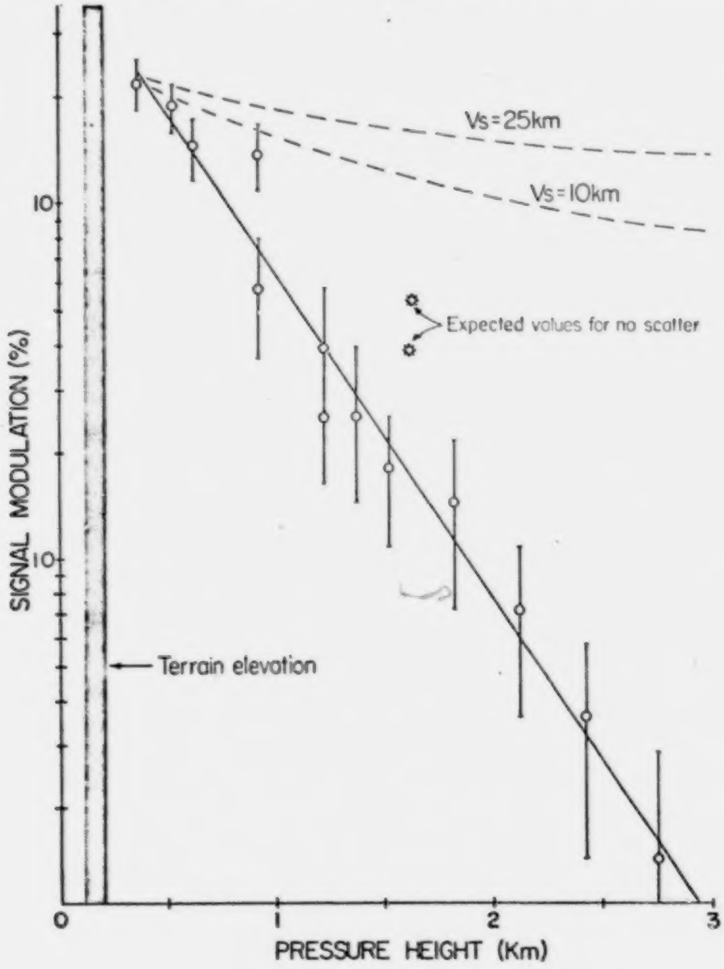

Figure 10. 3100 Å modulation versus height.

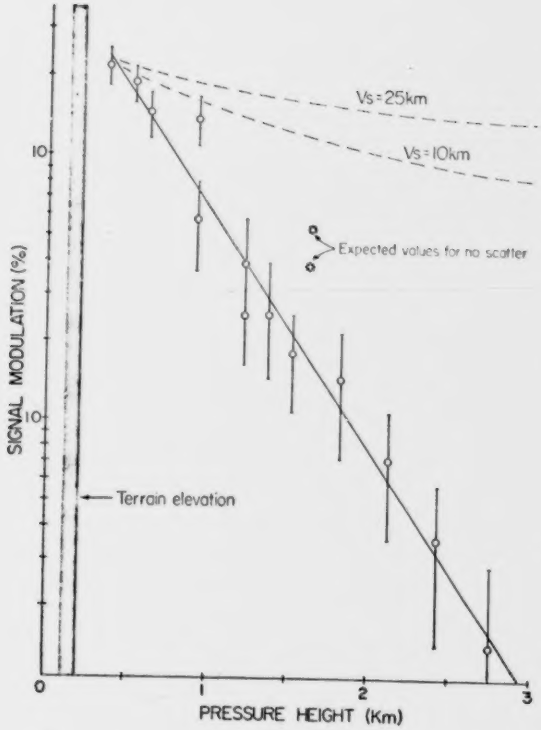

Figure 11. 3100 Å modulation versus height.

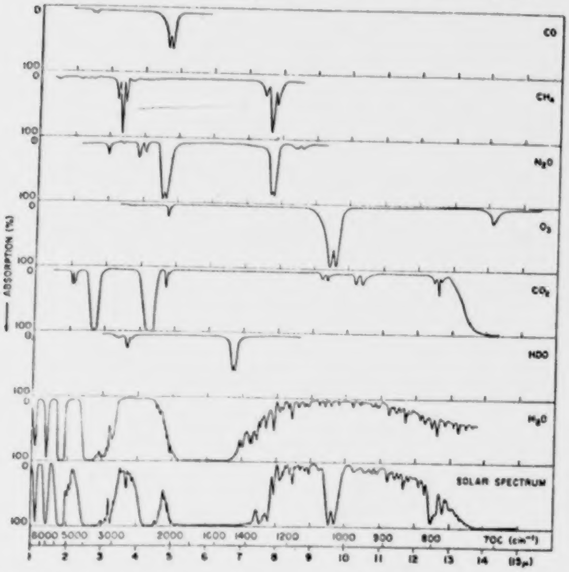

Figure 12. Comparison of the near-infrared solar spectrum with laboratory spectra of various atmospheric gases.[1]

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[1] Handbook of Geophysics and Space Environments. Air Force Cambridge Research Laboratories.

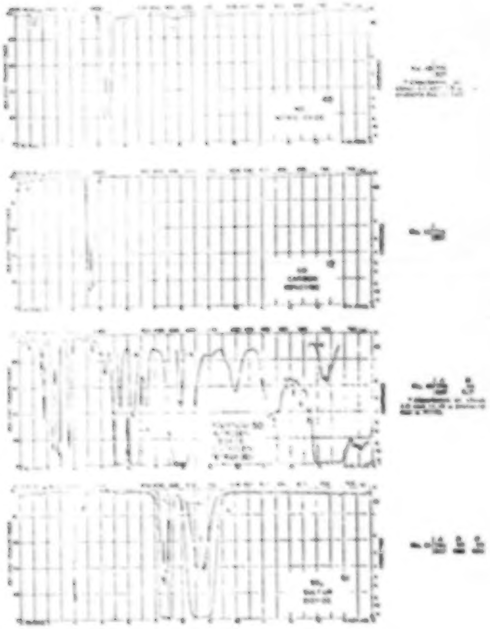

Figure 13. Absorption spectra for important atmospheric pollutants.[2]

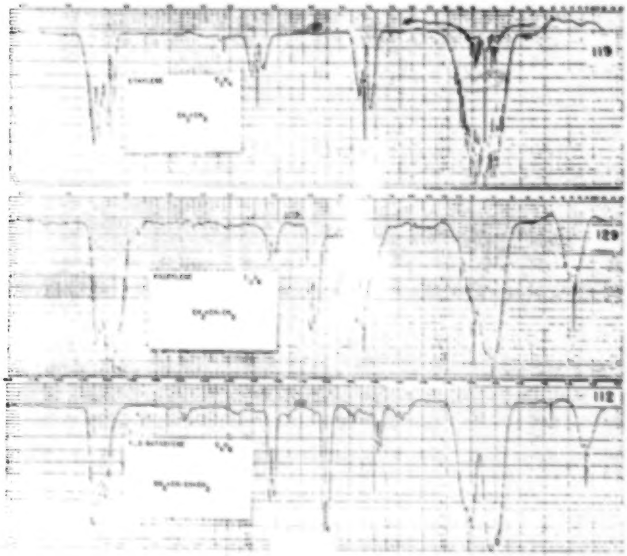

Figure 14. Spectra of three hypocarbons.[3]

---

[2] Catalog of Infrared Spectra for Qualitative Analysis of Gases. Beckman Reprint R-93.

[3] Infrared Spectra of Gases and Vapors. Vol. II, Grating Spectra by D. S. Earley and B. H. Blake, The Dow Chemical Company.

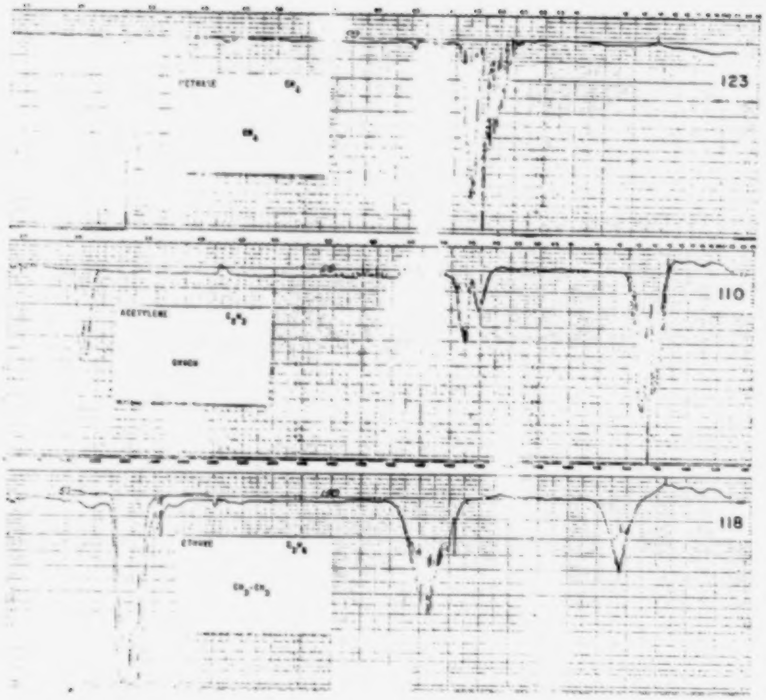

Figure 15. Spectra of three hypocarbons.[4]

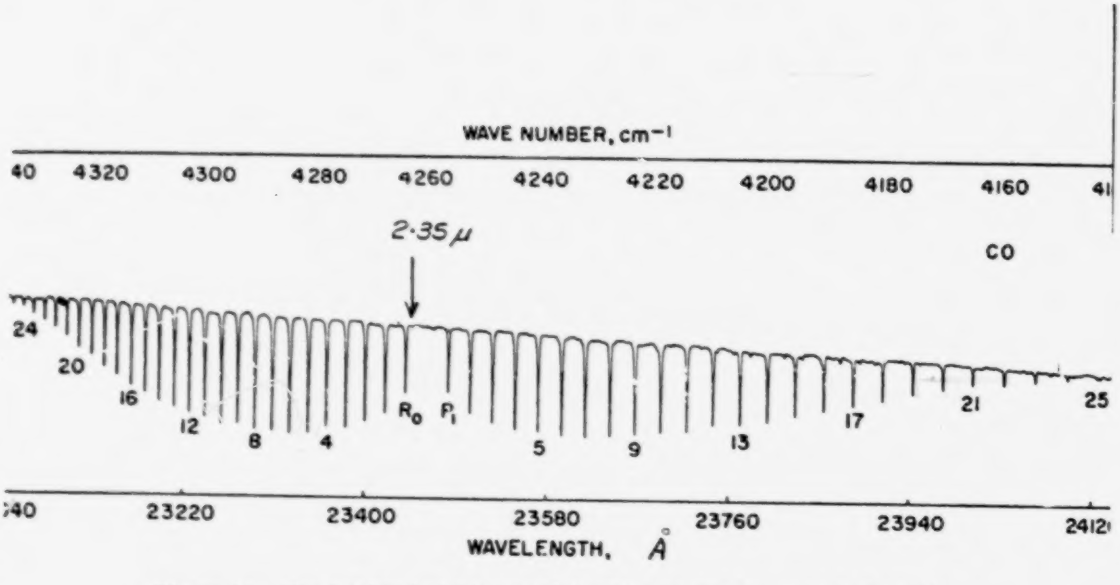

Figure 16. The 2-0 band of CO recorded with a 15 000 lines per inch grating with 20-cm pressure and 60-cm path (spectral slit about 0.15 $cm^{-1}$).

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[4] Ibid.

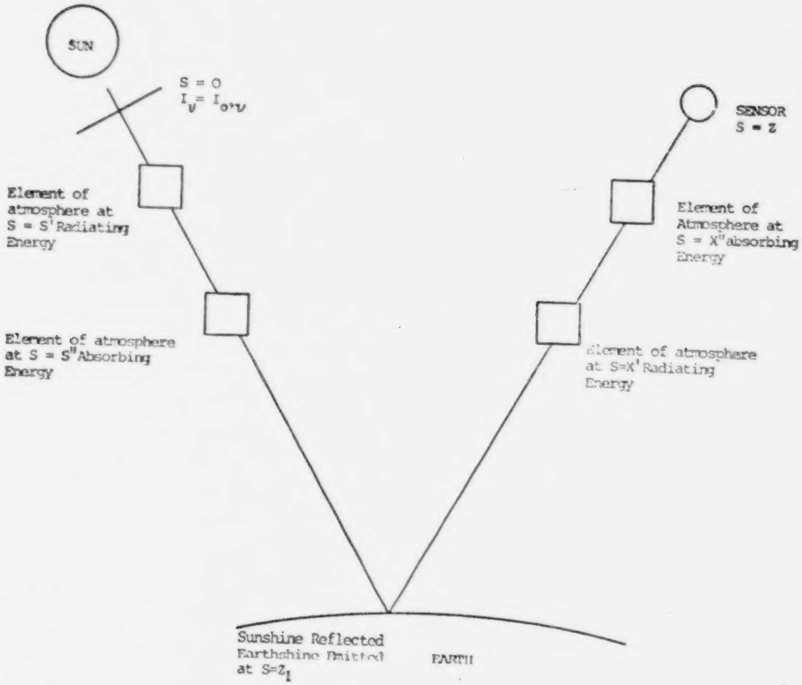

SUN
S = 0
$I_\nu = I_{o,\nu}$
SENSOR
S = Z
Element of atmosphere at S = S' Radiating Energy
Element of Atmosphere at S = X" absorbing Energy
Element of atmosphere at S = S" Absorbing Energy
Element of atmosphere at S=X' Radiating Energy
Sunshine Reflected
Earthshine Emitted
at $S=Z_1$
EARTH

Figure 17. Geometry for mapping conditions.

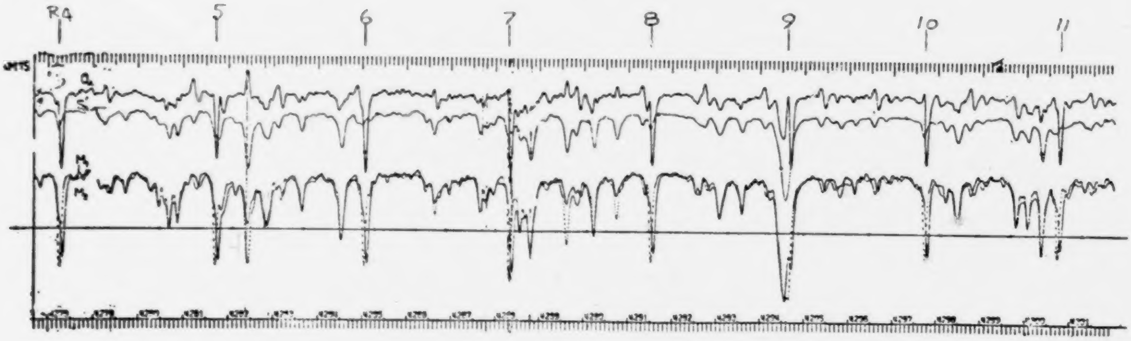


Figure 18. Solar spectrum showing 2-0 band of CO ($S_A$ is the solar spectrum; the marks show the CO line positions).

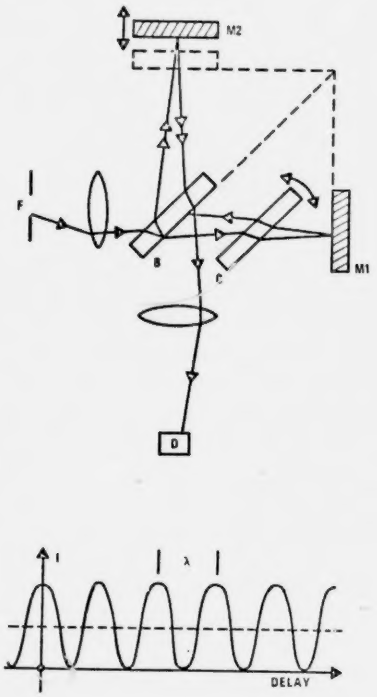

M2
F
B
C
M1
D
I
λ
DELAY

Figure 19. Fourier transforms.

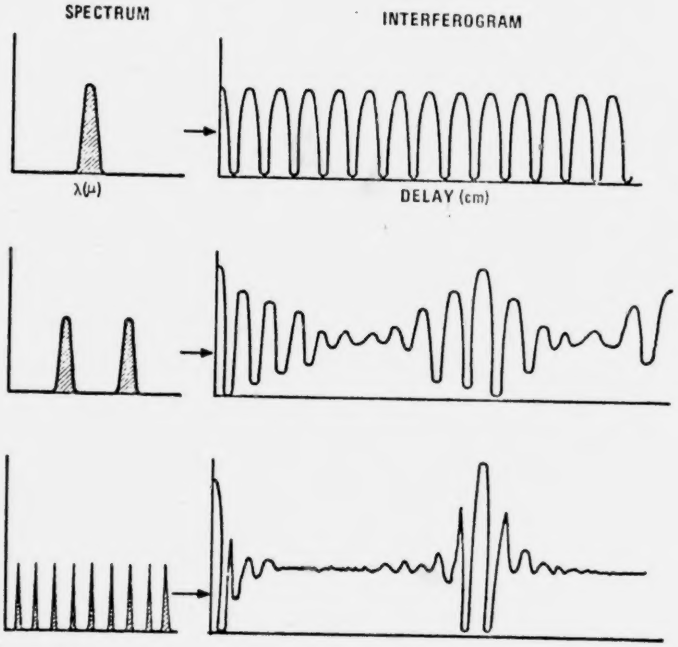


Figure 20. Correlation Michelson interferometer.

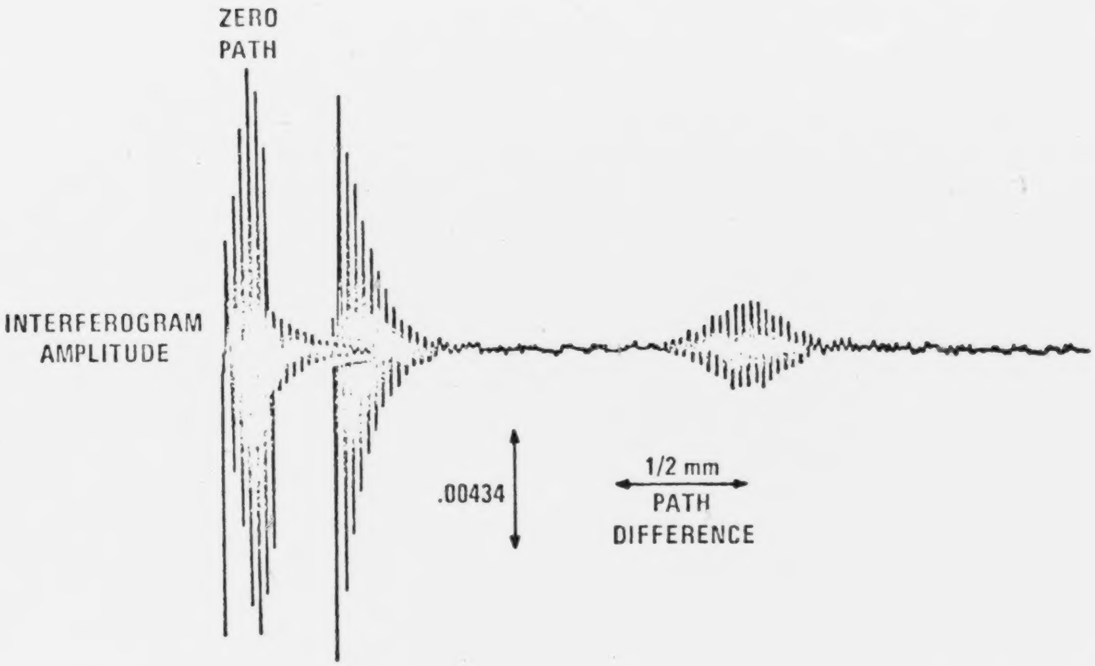


Figure 21. Interferogram.

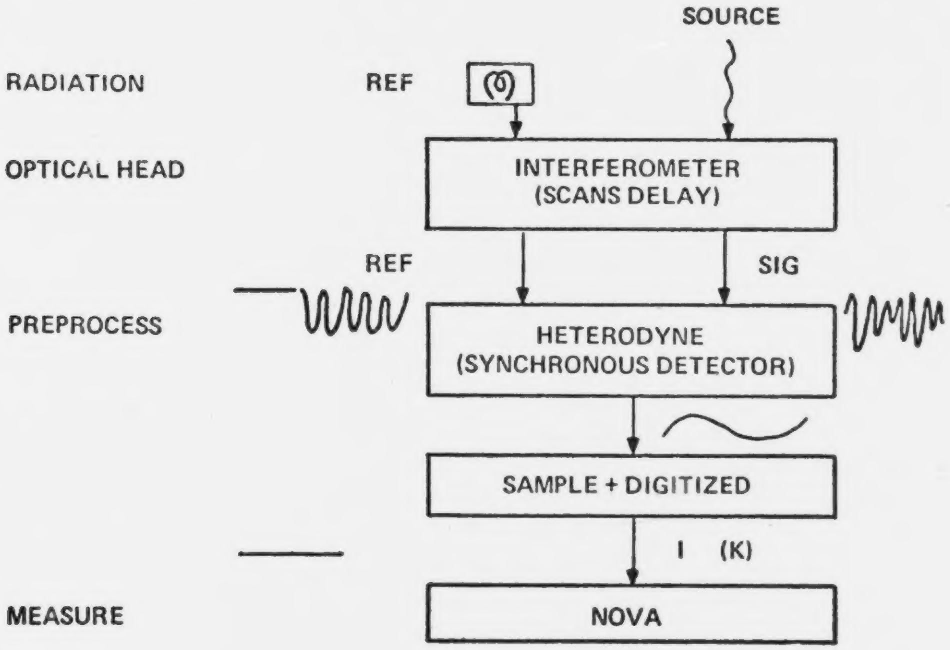

SOURCE
RADIATION
REF
OPTICAL HEAD
INTERFEROMETER
(SCANS DELAY)
REF
SIG
PREPROCESS
HETERODYNE
(SYNCHRONOUS DETECTOR)
SAMPLE + DIGITIZED
I (K)
MEASURE
NOVA

Figure 22. Interferometer system block diagram.

# SESSION IV

# EARTH RESOURCES OBSERVATIONS THROUGH ORBITAL SURVEYS

# USE OF DATA FROM SPACE FOR EARTH RESOURCES EXPLORATION AND MANAGEMENT IN ALABAMA

By Phillip E. LaMoreaux
State Geologist, Oil, and Gas Supervisor
Alabama State Oil and Gas Board

and

Dr. Harold R. Henry
Professor, Department of Civil and Mineral Engineering
University of Alabama

## Introduction

The University of Alabama, the Geological Survey of Alabama, and the George C. Marshall Space Flight Center are involved in an interagency, interdisciplinary effort to use remotely sensed, multispectral observations to yield improved and timely assessment of earth resources and environmental quality in Alabama. It is the goal of this effort to interpret these data and provide them in a format which is meaningful to and readily usable by agencies, industries, and individuals who are potential users throughout the State.

In order to assess the full range of potential users of these data in Alabama, a study was conducted by the University and the Geological Survey in 1971. During this study the several hundred potential users, contacted by project personnel, were informed of the remote sensing applications which can make use of observations from NASA's Earth Resources Technology Satellite (ERTS) and associated aircraft flights. These contacts were made by telephone calls, letters, personal conferences, and two symposia (one in Tuscaloosa and one in Mobile). The potential users were informed as to the possible applications of remote sensing from space in the areas of land use, resource inventory, environmental control and others. Only a few of the people contacted were already familiar with some aspects of remote sensing while the majority had no prior knowledge concerning this tool and its areas of applicability. In spite of this, the responses were enthusiastic and indicated that there would be a large amount of use of remotely sensed data after some degree of interpretation had been accomplished.

To give some idea of the breadth of possible users, categories, and uses in Alabama, the following results of this user study are given below.

Professionals who said they could use the data beneficially included urban planners, regional planners, foresters, geologists, ecologists, hydrologists, agronomists, biologists, physicists, astronomers, chemists, agriculturists, civil engineers, chemical engineers, agricultural engineers, mining engineers, geographers, limnologists, entomologists, architects, archeologists, demographers, lawyers, and university faculty members.

Possible categories of use were estimated to include land use, cartography, hydrology, geology, transportation, ecology, forestry, fisheries, mineralogy, meteorology, morphology, agriculture, oceanography, archeology, topographical mapping, demography, planning, and wildlife studies.

Detailed uses which were included as potentialities are flood control, soil studies, resource inventory, surface water studies, mineral exploration, ground water studies, water temperature studies, growth trends, surveying and mapping, air quality management, water quality management, disaster detection, damage evaluation, sediment transport, traffic studies, erosion control, irrigation, zoning, crop conditions, recreation, management, urban and regional planning, and pesticide studies.

The enthusiastic response from potential users, as described above, indicated that the planning of varied statewide applications of remote sensing oriented toward a broad base of grassroots users would be a timely and beneficial effort in Alabama.

Therefore, The University of Alabama, the Geological Survey of Alabama, and the Marshall Space Flight Center (MSFC) joined efforts to utilize this tool in statewide applications.

## Objectives

The objectives of this effort are:

1. To determine the applicability of remotely sensed data from ERTS for inventory and management of the natural resources and for the improvement of the quality of the environment in Alabama.

2. To apply photographic-interpretation techniques and statistical data management techniques to remotely sensed, multispectral observations and ground truth measurements of pertinent resource characteristics and environmental parameters to yield improved and timely assessment of the State of Alabama resources and environmental quality in an appropriately condensed format, which is meaningful to and readily usable by individuals in the various cooperating user agencies throughout the State of Alabama.

3. A long-range objective is to develop an effective procedure for processing and interpreting the remotely sensed data so that information in forms most suitable for ultimate users can be extracted and communicated to them. It is anticipated that the ultimate users will be public policy technicians and decisionmakers, as well as private industries.

## Discussion of Objectives

On the basis of the evaluation of the Apollo IX photographs it is anticipated that ERTS imagery could aid in the following areas related to water resources:

1. Determining areas of ground water movement

2. Determining areas of ground water discharge

3. Determining areas of ground water recharge

4. Determining areas of future sinkhole development

5. Determining areas of anomalies of low flow in streams

6. Determining areas of possible pollution through malfunction of salt water lines in oilfields

7. Determining changes in thermal patterns of reservoir and streams

8. Defining surface drainage and runoff patterns

9. Determining changes in sediment load in reservoirs

10. Locating lineaments, fault trends, domal structures, and other geological features.

Several additional aspects of the proposed project will be of particular interest to those engaged in traditional environmental engineering activities. For the sake of classification, they can be described as falling into one of the following problem-application areas.

1. Potamology
2. Lacustral Systems
3. Estuarine and Marine Systems
4. Predictive and Evaluative Hydrology
5. Atmospheric Pollution.

The water quality management studies related particularly to the rivers will be to determine the impact upon practical water resource management which can be effected by diurnal reporting of such parameters as stage, discharge, temperature, dissolved oxygen concentration, specific conductivity, pH, turbidity, and wind velocity by the strategically located Data Collection System (DCS) platforms.

Significant lacustral studies are made possible by the existence of relatively large navigation and hydroelectric impoundments on the rivers in the study area. The multispectral data for the impoundment areas will be evaluated for use in the preparation of isoplethic maps of depth, as well as for areal delineation. The data will also be assessed for their utility in monitoring remotely detectable types of extraneous materials, including turbidity and pollutants. It may be possible to detect, identify, and continue to observe benthic colonies of interest in the impoundments. The thermal infrared (IR) data may also furnish leading indications of known and expected thermal lacustral process occurrences important for effective water resource management.

Mobile Bay and adjacent portions of the Gulf of Mexico will be the site of estuarine and marine studies similar to the lacustral studies described above. In addition to their use for the determinations of depth, shoreline, and current mapping, the ERTS data will be used to monitor projected oil drilling activity in Mobile Bay for the occurrence of possible oil spills. Their utility for monitoring other pollutional sources already existent there is anticipated. The effect of this repetitive data of greater areal extent than any ever before available upon the effective management of these water resources will be assessed.

In the areas of predictive and evaluative hydrology, it is intended to relate spectral data to parameters obtained from ground-based instruments to provide better means of predicting discharge rates of the rivers. Also, similar data will be used to evaluate the accuracy of areal flood extents so predicted.

The improvement of prediction of stream discharge rates will be sought first by extrapolation of sparsely instrumented precipitation surveillance networks by use of the remotely sensed data. All resolution elements that look essentially the same to a photographic or electronic sensor will be grouped by MSFC's unsupervised classification algorithms. With such a classification it is anticipated that a few precipitation readings can then be extrapolated throughout a large area by identifying all other resolution elements which look spectroscopically similar to the element sampled by the ground-truth reading. A major electric utility having hydroelectric facilities in the study areas has indicated intense interest in the use of such improved predictive and evaluative methods.

Within the duration of the proposed study, existing State and Federal laws will begin to take effect for the abatement of significant air pollution problems within the study area. It is planned to use the ERTS data, insofar as it is possible, to indicate the magnitude of improvement which those abatement efforts produce. Birmingham and Mobile are the two major urban areas which will be studied in regards to air pollution, but there are other significant isolated pollution sources as well.

The conceptual approach to the use of remote sensing data in social and economic planning centers around communications and distribution. This emphasis complements other aspects of this effort which are concerned with collecting, organizing, and reporting in useful form hydrologic, geologic, oceanographic, and other environmental and earth resources data. Research described above resulted in an accurate identification of potential users and user categories. One major problem, however, will be in the transmission of data from analyst to the end user. There is an immediate need to translate the items of data output into a form usable by state agencies and law makers. The technical literature is virtually meaningless to public policy technicians and decisionmakers.

Only recently has the need for better management of the State's resources been recognized. Former policies, in regard to resource development, have been limited to discovery and advertisement of the assets which provide jobs and wealth; now, greater emphasis is placed upon technical analysis of the problem of economic growth and development and the need for appropriate legislative control over resources, land use, and other aspects of an orderly development process. The State's primary planning office, the Alabama Development Office (ADO), and its regional counterparts in the State's multicounty development district are just beginning to become operational.

The primary need within these planning units, beyond the considerable accomplishment of recognizing the need for organization in the first place, is for useful and current data relevant in managerial decisions. High on this list of data required is information on land use and water quality and quantity. Analysis of existing data is admittedly amenable to the understanding and forecasting necessary for establishing a policy on environmental quality, but data useful in the day-to-day implementation of a policy is still a major operational bottleneck in sound regulation. The possibility that ERTS-acquired data could eliminate this bottleneck will be investigated.

Planning agencies have a clear responsibility to document the extent and causes of environmental damages over extensive areas and place industrial expansion damage in proper prospective. Data from ERTS could probably be effective in such documentation. Moreover, managerial data generated, analyzed, or distributed by planning agencies is not limited in usefulness to the public sector. These agencies could provide a useful outlet for dissemination of information from ERTS and other sources to private industries, which would support and enhance their operations. These usages of ERTS data will require the closing of the communication gap between the scientific and the resource manager or public policymaker who will use the information digested from the remotely sensed data.

Since the long-range objective of the project is to develop an effective procedure for processing and interpreting the remotely sensed data and disseminating meaningful information to users (Fig. 1), the fact that information will be distributed to appropriate users from several intermediate stages of processing and interpretation is emphasized. Feedback from the users (Fig. 1) will be very important in refining the interpretation and processing in order to obtain the most useful form of the output.

Figure 2 is a diagram of data and information flows which emphasizes the disciplines which will be brought to bear in interpretation and evaluation at the University of Alabama and the Geological Survey of Alabama. This diagram shows that explicit evaluation and management of information flows will be performed on all information output to users. The indicated feedback will serve to allow an iterative approach to the preparation of the optimum formats for the output information.

## Description of System for Collecting Ground Truth

The investigation will extend throughout the entire State of Alabama, which is encompassed by the latitude and longitude values as shown in Figure 3. Ground truth by conventional means and by DCS platforms will be collected throughout the State during the investigation. Field data in support of these studies will be obtained primarily by direct field investigations and from existing data sources.

Ten DCS platforms, fully instrumented with appropriate sensors, are being planned for this investigation. Their locations are indicated on Figure 3. Three of the platforms will be on buoys in Mobile Bay and, in addition to contributing to this proposed study, will also contribute to the additional comprehensive study of Mobile Bay, which is being planned by the Marine Science Institute of the University of Alabama.

It is intended that each of the 10 DCS platforms be instrumented with eight sensors chosen to measure appropriate parameters which may be included in, but not necessarily limited to, the following list: precipitation, air temperature, soil temperature, humidity, soil moisture, river water level and discharge, ground water level, turbidity, salinity, pH, dissolved oxygen, specific conductivity, wind velocity, current direction and velocity, wave height, and tidal depth. Parameters to be measured at each of the 10 strategically located platforms will be chosen to give the most meaningful information at the particular location. The parameters for a particular platform may change during the investigation.

## Multistage Sampling Techniques

Multistage sampling utilizing satellite data, multispectral photography from aircraft flights, and ground truth data, with emphasis on the data obtained from the DCS platforms, will be performed over specific problem areas within the State. These are (1) a corridor from Tuscaloosa to Birmingham and (2) a corridor from Mobile Bay to the confluence of the Alabama and Tombigbee Rivers. Each of these corridors is approximately 60 miles long. The widths of the corridors will be variable depending upon the number of lines of flight that can be scheduled at each sampling time. It is anticipated that a minimum of three and a maximum of six flights over each area will be necessary for application of the multistage sampling techniques. The dates of flights will be scheduled to detect seasonal variations in vegetation and pollution, and the number of lines of flight in each corridor will be determined according to the availability of equipment and the sampling requirements. The time of day of the flights will be scheduled so that the aircraft data will provide an optimum supplement to the satellite data.

The choice of the Tuscaloosa-Birmingham area and the Mobile Bay area for the application of multistage sampling techniques stems from two main reasons, namely:

1. They both are principal growth areas in which environmental problems are increasing rapidly.

2. The first area is in the central part of the Warrior-Tombigbee drainage basin (outlined in Figure 3), which constitutes a complete hydrologic and geologic unit convenient for study. The second area is at the mouth of this river system, and all influents into the system must pass through this area.

It should be noted also that the ultimate use of the data from all levels will be to furnish information to planners, regulatory agencies, and private enterprise for the conservation, development, and use of the resources of Alabama. The 10 DCS platforms will be used to determine whether the automated collection of ground-based data from selected sites can be combined with aircraft and satellite data so that timely interventions (which otherwise might be impossible) may be accomplished to conserve resources and improve environmental quality.

## Expected Results of Investigation

It is anticipated that the results of this investigation will determine the feasibility of using remotely obtained spectral data in land use, planning, in inventorying and managing natural resources in Alabama, and in improving the environmental quality control in the State.

It is also anticipated that the participation and close liaison among the University of Alabama, the Geological Survey of Alabama, the George C. Marshall Space Flight Center, and the Alabama Development Office will be effective in developing a method and procedure for translating the remotely sensed data into information which can be effectively used by governmental agencies and industry by integrating it into the decisionmaking processes for environmental control, resource management, and land use.

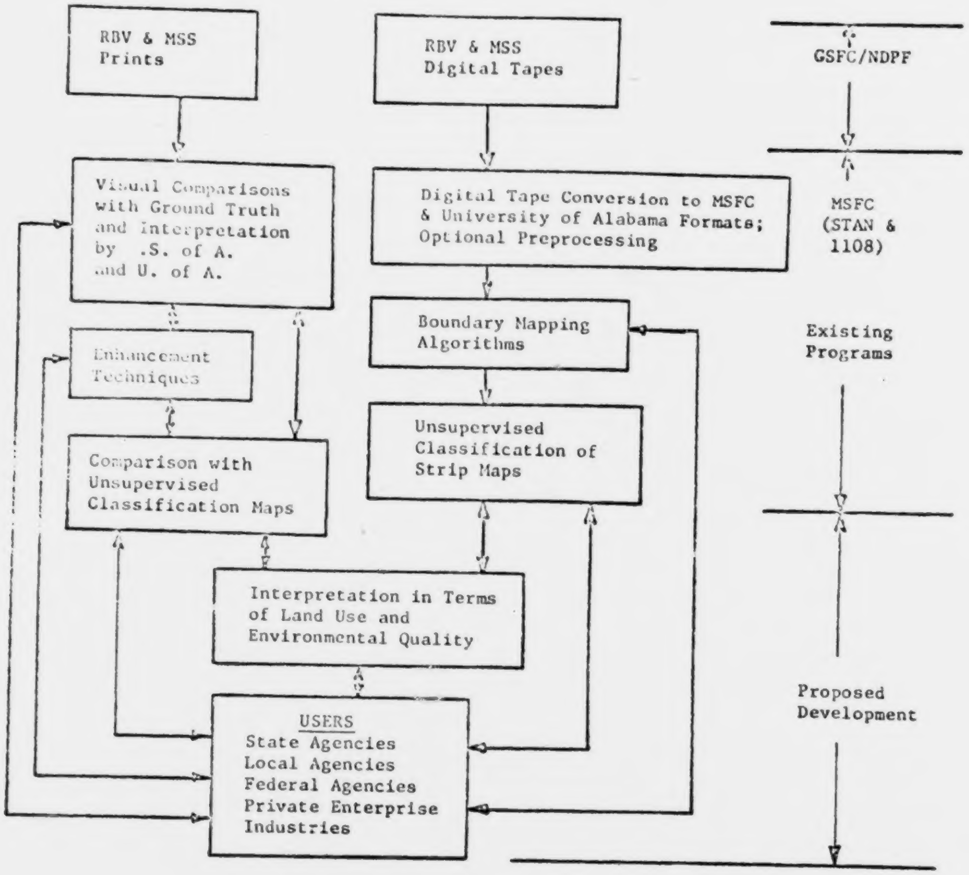

RBV & MSS Prints
RBV & MSS Digital Tapes
GSFC/NDPF
Visual Comparisons with Ground Truth and Interpretation by .S. of A. and U. of A.
Digital Tape Conversion to MSFC & University of Alabama Formats; Optional Preprocessing
MSFC (STAN & 1108)
Enhancement Techniques
Boundary Mapping Algorithms
Existing Programs
Comparison with Unsupervised Classification Maps
Unsupervised Classification of Strip Maps
Interpretation in Terms of Land Use and Environmental Quality
USERS
State Agencies
Local Agencies
Federal Agencies
Private Enterprise
Industries
Proposed Development

Figure 1. Block diagram of data flow.

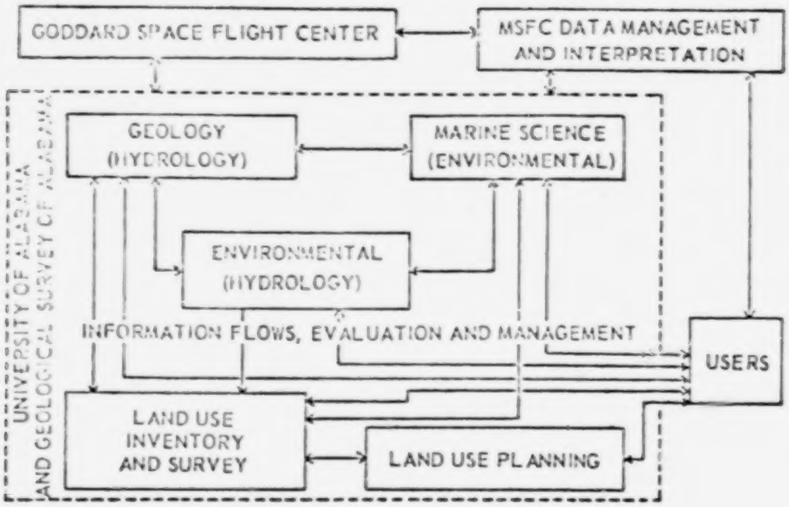
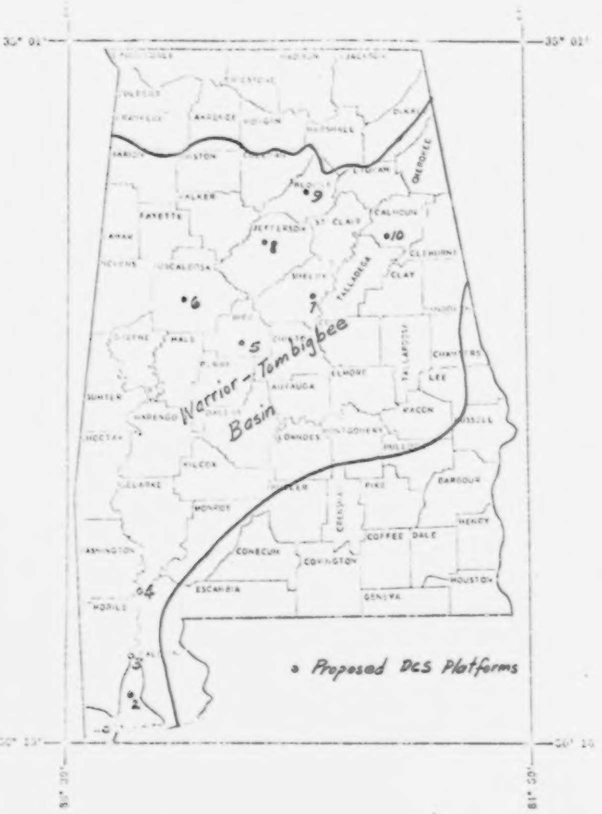

GODDARD SPACE FLIGHT CENTER
MSFC DATA MANAGEMENT AND INTERPRETATION
UNIVERSITY OF ALABAMA AND GEOLOGICAL SURVEY OF ALABAMA
GEOLOGY (HYDROLOGY)
MARINE SCIENCE (ENVIRONMENTAL)
ENVIRONMENTAL (HYDROLOGY)
INFORMATION FLOWS, EVALUATION AND MANAGEMENT
USERS
LAND USE INVENTORY AND SURVEY
LAND USE PLANNING

Figure 2. Diagram of data flow emphasizing disciplines, information flow evaluation, and feedback from users.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MORGAN
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CULLMAN
ETOWAH
CHEROKEE
BLOUNT
WALKER
FAYETTE
LAMAR
JEFFERSON
ST. CLAIR
CALHOUN
CLEBURNE
PICKENS
TUSCALOOSA
SHELBY
TALLADEGA
CLAY
RANDOLPH
BIBB
CHILTON
GREENE
HALE
PERRY
ELMORE
TALLAPOOSA
CHAMBERS
LEE
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MARENGO
DALLAS
AUTAUGA
MACON
RUSSELL
CHOCTAW
LOWNDES
MONTGOMERY
BULLOCK
WILCOX
CLARKE
BUTLER
CRENSHAW
PIKE
BARBOUR
MONROE
HENRY
COFFEE
DALE
WASHINGTON
CONECUH
COVINGTON
HOUSTON
ESCAMBIA
GENEVA
MOBILE
BALDWIN
Warrior - Tombigbee Basin
1
2
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10
• Proposed DCS Platforms

Figure 3. Location of test area (the entire State of Alabama).

# A DATA ACQUISITION SYSTEM (DAS) FOR MARINE AND ECOLOGICAL RESEARCH FROM AEROSPACE TECHNOLOGY

By Richard A. Johnson
Manager, MSU-MTF Research Center
Mississippi State University

## Abstract

This paper represents the efforts of researchers at Mississippi State University to utilize space-age technology in the development of a self-contained, portable data acquisition system for use in marine and ecological research. The compact, lightweight data acquisition system is capable of recording 14 variables in its present configuration and is suitable for use in either a boat, pickup truck, or light aircraft. This system will provide the acquisition of reliable data on the structure of the environment and the effect of man-made and natural activities on the observed phenomenon. Utilizing both self-contained analog recording and a telemetry transmitter for real-time digital readout and recording, the prototype system has undergone extensive testing at the Mississippi Test Facility (MTF). Currently undergoing component performance upgrading, the prototype system has been utilized in several environmental science investigations associated with air pollution investigations and weather modification. It is currently being used on the Eco-System Research Project for marine data acquisition.

## Acknowledgment

The author gratefully acknowledges the contributions of Dr. Lewis R. Brown, Dr. Richard E. Forbes, Dr. Michael R. Smith, G. S. Pabst, and M. L. Jones to the development of this prototype system and the preparation of this paper. This work was accomplished under NASA Grant NGL 25-001-028, NGL 25-001-032 and NGL 25-001-040.

## Introduction

The recent emphasis on environmental science research in the U.S. has provided substantial impetus to research programs in the general area of marine ecologies. Researchers are developing numerous prediction methods for use in the control of air pollution; prediction of ecological alterations caused by pollutants in fresh water, estuaries, and the marine environment; detection of contaminants in aquatic and terrestrial ecological systems; and related phenomena. Airborne remote sensing has opened up almost unlimited horizons for the collection of resource data from aircraft and satellite platforms; however, at this stage of development the methods require sufficient amounts of accurate ground-truth measurements to substantiate the overall base line.

This paper presents the results of efforts by researchers at Mississippi State University to utilize space-age technology in the development of a self-contained data acquisition system for use in marine, ecological, and environmental research. The system was originally developed at the NASA/MTF with the aid of personnel provided by the MTF contractor, the General Electric Company. The basic system was developed with off-shelf components and excess aerospace assemblies and was initially designed to be mounted in a light, single-engine aircraft to provide economical operation for small investigations in atmospheric diffusion and weather modification. In addition, the data acquisition and data processing facilities of the NASA/MTF were utilized to the maximum in providing real-time processing and graphical and tabular presentations of the experimental data.

The data acquisition system is capable of handling 18 independent measurements in its present configuration; however, onboard recording capability exists for only 14. The experimental data may be telemetered directly to the data handling center at the NASA/MTF or may be recorded onboard as the individual situation requires. Most of the equipment utilized in the development of the data acquisition was performing service in another capacity prior to its utilization in the present system.

## System Development

Criteria. The development of the original Airborne Data Acquisition System (ADAS) resulted from a direct requirement for experimental data to support results predicted by a computerized numerical simulation program. In addition, it was desired to use the data acquisition and data processing facilities at MTF and at the same time provide a system which could operate independently of these facilities in the data acquisition phase of an investigation. These considerations led to the development of an ADAS with both onboard recording and telemetry capabilities. In addition, it was desired to develop a self-contained system which did not depend upon the aircraft power and flight systems. This feature provides for a more flexible system in that it can be installed in an aircraft with either 12-volt or 24-volt electrical systems and also it is easier to satisfy Federal Aviation Regulations governing the installation of the ADAS in an aircraft.

Hardware Description. Development of component hardware was initially divided into three main categories: (1) equipment available directly usable or requiring only minor modifications, (2) equipment from outside procurements, (3) equipment requiring major modifications and/or new design. In order to satisfy the requirements delineated in the discussion on criteria, the main emphasis was on utilizing components which could be interfaced together with a minimum amount of design and fabrication requirements. The telemetry equipment obtained was an excess, Saturn V, third-stage rocket unit. The seven-channel analog recorder, power supplies, signal conditioners, resistance bridges, and the various sensing devices were procured separately. All interface equipment, antenna hardware, sensor and transducer mounts, remote control and monitor panel, and the overall system configuration was designed especially for this application and fabricated at MTF.

## General Description of the Data Acquisition System

The assembled DAS is set up for a bench checkout in Figure 1. In the upper foreground is the telemetry transmitter unit and mixer amplifier (1); in the lower foreground is the medium gain signal conditioner amplifiers (2); and in the rear is the analog seven-track recorder (3); the left panel mounts resistance bridges and calibration, control, and interface patching (4); the special power supplies are floor mounted to the rear of this assembly (5); shown in the foreground is the remote power and control switches and the signal monitor display (6) mounted within close proximity to the operator, enabling the entire unit to be controlled in the cab of the boat, truck, or aircraft. The complete DAS is capable of being installed by two men in an 18-ft boat or pickup truck, with sensors mounted in the water and calibration and ground check completed within 1 hour. The overall dimension of the electronics package is 25 by 27 in. and 14 in. high. The total weight of the DAS, including all equipment and sensors, is slightly less than 250 lb. The dc batteries are mounted in spillproof canisters.

## Operational Mode

Airborne Operations. Flight operations were conducted during 1970 at the NASA/MTF to test the operation of the DAS and the quality of telemetry data received and processed by the MTF Data Handling Center (DHC). Numerous data runs were made at various times to flight check, calibrate and establish operating characteristics of the individual measurements. Extensive data collection was performed on rocket exhaust plumes during the static firings of the Saturn V first- and second-stage booster rockets at MTF. Pre- and posttest calibrations were run between the aircraft and the DHC to establish reliability and accuracy of data acquired during static-firing measurements.

Prior to an airborne mission, the ADAS is bench checked and calibrated in the laboratory, and the calibrations and operational characteristics are checked after installation of the ADAS in the aircraft. In most cases, it takes approximately 1 hour to warm up and ground check the unit.

Marine Operations. From June 1971 until the present, utilization of this system has been devoted to ecological and marine investigations. While this system can be utilized in a boat, truck, and aircraft, the initial phase has involved its use (mounted in a van) in the Eco-System Research Project area at [illegible], within the function of Mississippi State University's Environmental Science Laboratory at MTF. This laboratory is part of the MSU Research Center and is dedicated to the solution of pollution problems in the Central Gulf South area. The Eco-System Research Project is a series of ponds and artificial streams wherein simulated ecological-systems can be studied. In these ponds, special sensor packages will continually measure selected parameters, which are transferred to the instrumentation van via cables and connected to the data acquisition system for analog recording or telemetry transmission to the DHC.

## Processing of Acquired Data

Utilization of the MTF/DHC for processing of the acquired data has proved to be significantly advantageous both from the standpoint of accuracy of the results and the speed of data reduction. For missions conducted within about 10 statute miles of the NASA/MTF, the acquired data are usually telemetered to the MTF/DHC for real-time processing and the analog recorder is used as a backup system. When missions are conducted farther away, they require the use of the analog recorder as the prime means of data acquisition, the analog tapes can be processed at either the MTF/DHC or other equivalent facilities.

The MTF/DHC has the capability to receive, condition, and record the data from an FM telemetry system using an analog receiving station and a Scientific Data SDS-930 digital computer system, or to replay a prerecorded tape through a wideband recorder and into the computer.

The digital data are corrected using calibration tapes and other established methodology resulting in a digital Engineering Units tape ready for storage and later retrieval or to be stripped out as hard copy data.

## Application to the DAS to Environmental Science Investigations

The DAS has been used to obtain data in several environmental science investigations. Included in these investigations have been probings of the exhaust plume generated during the static firing of rocket engines, delineation of the structure of natural clouds under various meteorological conditions, quantitative contamination of aquatic and terrestrial ecological systems in support of studies directed toward predicting the ecological alterations caused by pollutants in fresh water, estuaries, and the marine environment.

The accepted data gathering procedure, prior to the introduction of this system to marine and ecological research, is best illustrated by Figure 2. Manual measurements require at least one individual, sometimes two, for each parameter measured, if they are to be performed simultaneously. Compromises must be worked out as the amount of personnel required to make 6-12 discrete measurements, at the same time, would be unrealistic for most projects conducted in the field. The application then of this system to the problem of recording ecological data allows all parameters to be recorded simultaneously and utilizes only two individuals to operate the system.

The DAS was designed originally to acquire data related to the growth and dissipation of rocket exhaust plumes, which are generated during the static firing of the S-IC and S-II rocket engines. The exhaust cloud, or plume, generated during the static firing has many characteristics which resemble a natural cloud. Considerable interest has been exhibited toward the possibility of using this isolated cloud as a well-defined model for weather modification research. These interests are directed at both the modification precipitation and electrostatic discharge in natural clouds and thunderstorms. In addition, the exhaust cloud could cause an air pollution problem in the event that toxic additives are used in the propellants. It was desired to determine the diffusion characteristics of the exhaust plume of various rocket engines under various meteorological conditions.

The investigations on the effect of various meteorological conditions on the structure of natural clouds were conducted in approximately the same manner as for the rocket exhaust clouds. The primary difference in the nature of the operations was that the natural cloud missions often extended over 3- to 5-hour periods and over geographical locations up to 100-500 miles apart. In these cases it was desirable to recalibrate for each particular cloud probe, which would typically require 5-10 penetrations. The handling of such volumious calibrations would be very difficult if manually recovered, but is expeditiously processed by computer and significantly increases the reliability of the output.

Research concerning the prediction of ecological alterations caused by pollutants in fresh water, estuaries, and the marine environment and by the contamination of aquatic and terrestrial ecological systems is greatly facilitated by accurate and timely data collection in the field through the use of Field Monitoring Systems (Fig. 3) utilizing the DAS. This would allow collection of data from field locations for subsequent use in simulating field conditions in the laboratory and pilot plant ecological systems. In addition, the immediate review and analysis of data acquired from the local environment would be available for use by local, State, and Federal planning functions for application to existing environmental problems.

## Conclusion

The DAS discussed herein represents a unique application of aerospace technology and excess hardware to problems in the environmental sciences.

The development of the DAS has provided an economical means of obtaining ecological, marine, and meteorological data using this portable system in a boat, truck, or aircraft.

The utilization of the data processing facilities at the NASA/MTF, in conjunction with the airborne data acquisition missions, has provided a real-time data processing capability which is extremely valuable for basic research investigations and programs which involve the evaluation and development of sensors and sampling techniques.

The availability and accessibility of Government excess equipment, with the unique innovations of application engineering and aerospace technology, provide the low-budget researcher a level of capability never before attained. Since most university-sponsored research is through State or Federal funding, this gain in capability and knowledge, and at the same time minimizing overall project cost, provides continuing benefits from the aerospace program long after the need of the original application has expired. Any enhancement to the transference of environmental science research into useable application toward solving the pollution and the ecological problems facing the South Gulf area in particular, and the U.S. in general, will be an immediate benefit to us all.

## References

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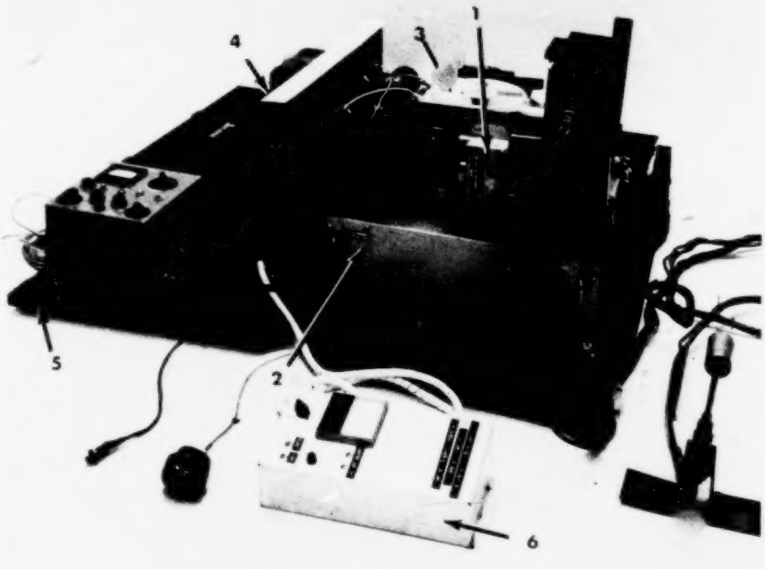
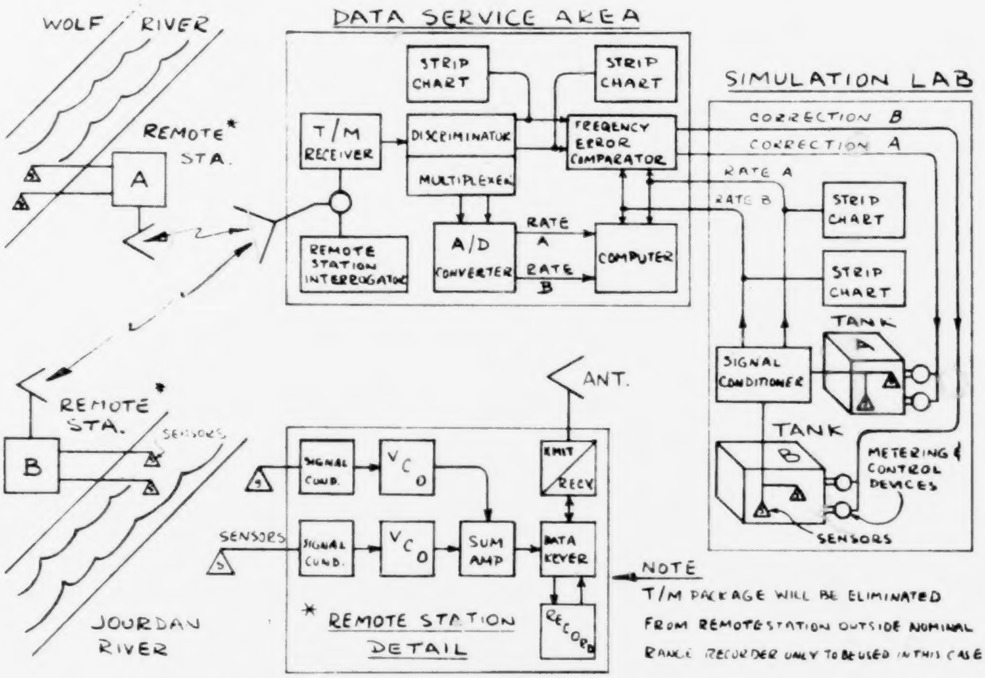


Figure 1. Marine Data Acquisition System (DAS).

Figure 2. Former data gathering procedure (manual method).


WOLF RIVER
REMOTE* STA.
A
DATA SERVICE AREA
STRIP CHART
STRIP CHART
T/M RECEIVER
DISCRIMINATOR
MULTIPLEXER
FREQENCY ERROR COMPARATOR
REMOTE STATION INTERROGATOR
A/D CONVERTER
RATE A
RATE B
COMPUTER
SIMULATION LAB
CORRECTION B
CORRECTION A
RATE A
RATE B
STRIP CHART
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TANK
A
SIGNAL CONDITIONER
TANK
B
METERING & CONTROL DEVICES
SENSORS
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B
SENSORS
ANT.
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NOTE
T/M PACKAGE WILL BE ELIMINATED
FROM REMOTESTATION OUTSIDE NOMINAL
RANGE RECORDER ONLY TO BE USED IN THIS CASE

Figure 3. Field Monitoring Systems.

# SATELLITE OBSERVATIONS OF TEMPORAL TERRESTRIAL FEATURES

By George Rabchevsky
Allied Research Associates, Inc.

## Abstract

In the 11 years since the launch of the first orbiting meteorological Television and Infrared Observation Satellite (TIROS I) on April 1, 1960, over 1 million pictures of the earth have been recorded by 25 weather satellites. During the 10 manned orbital flights of the Gemini program, the astronauts took over 2400 seventy mm color photographs; coverage obtained from Apollo VI, VII, and IX missions comprises a total of 2100 pictures. This coverage, at various times, scales, and geographic locations, has given us a unique look at the dynamic features of the earth on a daily, weekly, seasonal, and yearly basis. This report will review some of these observations and their utility to the various earth science disciplines.

## Acknowledgments

The author gratefully acknowledges the help of Mr. John E. Sissala in the preparation of this paper, which is based largely on his talk entitled, "The Utilization of the Various Time Scales of Meteorological Satellite Observations to Monitor Terrestrial Changes," presented at the First Western Space Congress, sponsored by the Vandenberg Scientific and Technical Societies Council, held on October 27-29, 1970, at Santa Maria, California.

The manuscript was also reviewed and useful comments made by the following individuals, whose cooperation is also gratefully acknowledged: Mr. Don Kulow, U.S. Geological Survey, EROS Program; Mr. Morris Deutsch, U.S. Geological Survey, EROS Program; and Dr. Paul McClain, National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite Center.

## Introduction

The photographic coverage of the earth's surface obtained from the Gemini and Apollo missions ranges in resolution from 30 to 200 ft. Unlike the meteorological satellite coverage, however, the photography[1] is not repetitive and is confined only to the lower latitudes. On the other hand, the experimental, meteorological, polar-orbiting satellite (Nimbus) and the improved TIROS operational meteorological satellite (ITOS) permit two observations of any point on the earth every 24 hours, once during the daytime and once during the nighttime. An even more frequent daily coverage is provided by the Applications Technology Satellite (ATS) series, placed in geosynchronous[2] stationary orbit 22 300 miles above the equator. Every 20 min a picture is taken of diurnal conditions over the Atlantic and Pacific Ocean regions. Their application to nonmeteorological studies, however, is not yet fully explored.

Application of satellite data to earth resources and environmental studies depends largely on the resolution[3] of the photographs and imagery. Only data from the Nimbus satellite series is adequate for this purpose, besides the Gemini and Apollo photography. Nimbus satellites with ground resolutions from 0.5 to 7.5 n. mi. at the subpoint have given us a new perspective to view our continually changing atmospheric and terrestrial environment.

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[1] Photography - The production of a permanent or ephemeral image of a subject on a medium which is directly exposed to electromagnetic radiation emitted or reflected from the subject, or transmitted through the subject, and is affected by the radiation in direct proportion to the emission, reflection, or transmission characteristics of the subject.

[2] Geosynchronous - Same as earth synchronous.

[3] Resolution - The minimum distance between two adjacent features, or the minimum size of a feature, which can be detected by a photographic or an imaging system. For photography, this distance is usually expressed in line pairs per millimeter recorded on a particular film under specified conditions; as displayed by radar, in lines per millimeter. If expressed in size of objects or distances on the ground, the distance is termed "ground resolution."

When two or more satellites are in orbit simultaneously, the capability to view each point on the earth increases. This capability has not been used extensively yet, although it offers attractive advantages for some applications. Many features would not exhibit any change even if viewed from the same angle each day, because the parameters being sensed do not change significantly during short time scales. Movements along geologic faults or polar ice shelf boundary changes are an example of this situation. Thus, while changes of some features may be observed daily or more often, it is at times necessary to make longer temporal comparisons of imagery to determine the significance and amount of change. Table 1 summarizes some of the temporal terrestrial features and the time scales of observations required for their detection.

The Earth Resources Technology Satellite (ERTS) is planned for launch by NASA for March of 1972. The expected 18-day repeat coverage from ERTS will enable us to map dynamic terrestrial features (coastal processes, erosion, floods, vegetation bloom) and classify events and landforms (geologic hazards, drainage networks, lakes) on a regional scale for the first time. The presently available satellite data are meanwhile generating background studies for future more detailed and local applications of the ERTS photographs and imagery.[4]

## Oceanography

Sea surface temperature observations are proceeding actively using satellite radiometers.[5] Over cloud-free ocean regions, surface temperatures have been measured with an accuracy of ±2° K[6] [1,2,3]. The Nimbus and ITOS satellites have the capability to sense the ocean surface temperature every 12 hours.

Current Boundaries. Nimbus radiometers have sensed thermal boundaries of major ocean currents (Fig. 1). Changes in these boundary positions have been observed on a daily and weekly basis. Boundary changes along the north wall of the Gulf Stream have been computed for a 2-month period using those data [4]. Since currents could be utilized or avoided to save shipping time, ship routing will depend on accurate knowledge of the location, extent, and velocity of currents. It has also been suggested that spaceborne oceanographers might be able to see current shears due to modifications of wave characteristics, waves from islands, undersea topography, color due to contaminants, or some other factors [5].

Ocean Upwelling. Some areas of upwelling have been studied in detail. Changes in their thermal patterns have been correlated with concentrations of fishing and phytoplankton activities [6]. A 3-day interval upwelling pattern change of the Somalian coast is illustrated in Figure 2. Yearly views of this area indicate the recurrence of this thermal pattern during the same season, suggesting that the commencement of upwelling can be monitored with satellite data [7].

Analyzed at hourly intervals just west of the Galapagos Islands, ATS III pictures have suggested the presence of upwelling within the sunglint patterns [8,9]. Similar anomalous patterns in areas of sunglint are usually observed daily by the Nimbus and ITOS satellites (Fig. 3).

The deep blue water along the upper west and east coasts of Taiwan (Fig. 4) are areas of upwelling, potential sources of new fishing grounds. Timely observation of such drastic temperature changes is imperative for proper management and conservation of ocean resources.

Sea State. Unusual dark patches observed within the sunglint patterns on Nimbus and other satellite photographs seem to be also due to areas

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4. Imagery - The pictorial representation of a subject produced by electromagnetic radiation emitted or reflected from a subject, or transmitted through the subject, and detected by a reversible-state physical or chemical transducer whose output is capable of providing an image.

5. Radiometer - A radiation-measuring instrument having substantially equal response to a relatively wide band of wavelengths in the infrared region. Radiometers measure the difference between the source radiation incident on the radiometer detector and a radiant energy reference level.

6. K - identifies Kelvin thermometric scale; 0° K is absolute zero, -273.13°C or -459.4°F.

of calm water in the midst of rougher sea surfaces (Fig. 3). Hourly reflectance changes of these dark spots have also been observed on the ATS imagery. It has been suggested that these dark spots may be correlated with areas of calm water and upwelling [8,9].

The complex nature of the ocean surface is revealed in Figure 5, as seen by the crew of Apollo 7 on October 15, 1968, from 100 miles in space. The water around the islands of Socotra and the Brothers are caught in the sun's reflection, revealing a complex surface phenomenon impossible to view by ordinary means. Situated just off the east African coast and north of one of the strongest upwelling areas in the world, the islands form a deflective barrier to the northeastward movement of the cold, upwelled water. The vortices, slicks, swells, and other lines which are visible reveal current direction, internal waves, and regions of convergence and divergence. Repetitive observations of such features are invaluable in oceanographic research.

Polar Pack Ice Boundaries. Pack ice boundaries have been established for both polar seas using satellite imagery [10, 11, 12]. Month-to-month and year-to-year changes in the Antarctic pack ice boundaries north of the Weddell Sea have been determined from Nimbus II and III pictorial imagery (Fig. 6) [13, 14].

Arctic ice and water temperature boundaries have been determined using satellite data [15]. Discrimination of older ice from newer ice near the ice and water boundary is also possible, as is detection of weekly and monthly thermal changes in these boundary positions. Current technology cannot provide a continuous or integrated measure of ice cover. Present estimates are based almost entirely on point samples, often obtained with considerable difficulty under adverse conditions. Better information is needed on the total quantity of water stored as snow and ice in a given area, and repetitive sampling from satellites may provide such information.

Ice Concentrations. Polar (and temperate climate) ice concentrations can be extracted from satellite data [11, 15, 16, 17]. Daily and weekly changes at specific locations have been observed and corroborated with conventionally gathered visible and infrared[7] data. In general, new, thin ice cannot be detected unless covered by snow. Ice concentrations from 1 to 0.3 are often evaluated as ice free because of limitations of satellite system resolutions. There is usually good agreement with ice charts of ice amount between 4 and 0.7 and excellent agreement of ice amounts greater than 0.7. Changes of concentration from one of these classes to another have been reliably determined.

The British Arctic Survey (BAS) has been receiving regular ESSA satellite photo coverage of the Antarctic Peninsula area since 1967. These pictures have proven to be of real benefit to observe the distribution of pack ice to facilitate the passage of the Survey's ships to Antarctic stations. The ships' ice reports are continually used with the satellite pictures to develop confidence in the ice amounts derived from satellite data.

Off-Shore Leads. The formation of polar off-shore leads has also been observed on satellite photographs (Fig. 7). An interesting phenomenon is the annual development of leads at specific locations at approximately the same time of year. Nimbus I, II, and III in late August 1964, 1966, and 1969 observed a lead development off the east coast of the Antarctic Peninsula in the Weddell Sea [18]. Similar observations have been made in the Arctic.

These features can be used as corridors by ship traffic to reach remote scientific stations. The seasonal behavior of such leads could be easily monitored through repetitive satellite observations. The frequency of such observations would increase during the spring and fall seasons (daily observation) and decrease during the rest of the year (monthly observations).

Iceberg and Ice Floe Tracking. Large tabular icebergs have been observed and their movement followed in Antarctica (Figs. 8 and 9), while large ice floes have been tracked off the east coast of Greenland [19]. The first tabular iceberg to ever be viewed from space was seen by Nimbus I in 1964 at the junction of the Filchner Ice Shelf and the Antarctic Peninsula [20]. Nimbus III views of this area in 1969 revealed that this 70-n.-mi.-long iceberg had moved into the ice pack, leaving an indentation in the coast-line identical to the iceberg's shape. The Environmental Sceince Services Administration (ESSA) satellite observations of this area during the intervening years would probably establish the time of separation and possibly the rate of movement of this feature through the Weddell Sea.

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[7] Infrared - Pertaining to or designating the portion of the electromagnetic spectrum with wavelengths just beyond the red end of the visible spectrum, such as radiation emitted by a hot body. Invisible to the eye, infrared rays are detected by their thermal and photographic effects. Their wavelengths are longer than those of visible light and shorter than those of radio waves, light rays whose wavelength is greater than 700 nm milli-microns.

Two giant icebergs were observed by the ESSA-III satellite during the 1967-68 Antarctic summer. They were moving westward along the coast in the Weddell Sea. Movement and size of these icebergs were compared with reports from Antarctic stations. It is suggested that one or both of these icebergs may be derived from that which calved from the Amery Ice Shelf in late 1963 [21].

## Hydrologic Applications

Snow Boundaries. Useful snow information has been extracted from satellite data. Daily and weekly changes of the snowline in the upper Missouri-Mississippi River Valley were mapped from satellite data with very good agreement with the ground derived snowline [22]. Figure 10 is an example of a snowfall boundary change along the eastern part of the U.S.

Weekly changes in the U.S. snow boundaries have been automatically determined from ESSA and the Advanced Vidicon (television) Camera System (AVCS) imagery through the use of a computer which stores all reflectance values, for each data point, in digital form. Upon command, an array of the lowest reflectance for each data point is displayed as a Composite Minimum Brightness (CMB) chart [10]. Snow and ice boundaries are readily apparent, as the transient cloud patterns are eliminated by this procedure.

Weekly snow-coverage changes monitored by meteorological satellites in river basins in the southern Sierras of California have correlated within ±5 percent of aerial snow survey measurements [23]. Figure 11 is an Apollo IX view of the southern Sierras. Similar photographs from the forthcoming ERTS system will greatly enhance the mapping of biweekly and monthly scales.

Monthly and annual changes of snow coverage in the Himalaya and Hindu Kush Mountains have been observed but, as yet, no quantitative evaluation of these changes has been made (Figure 12) [24]. Similarly, the three Nimbus IV Image Dissector Camera (TV) System (IDCS) pictures, taken over a period of 1 month (Fig. 13), show a rapid decrease in snow cover on the peninsula of Kamchatka.

Inland Lake Temperatures. The seasonal progression of the average surface temperature of Lake Michigan has been obtained using the Nimbus High Resolution Infrared Radiometer (HRIR) data [25]. Figure 14 shows Lake Michigan temperature patterns during 1966 from Nimbus II HRIR. Although Nimbus surveyed the Lake Michigan area nightly, observation of the entire lake was limited on many occasions by cloud cover and by sunlight interference [26]. Such observational constraints will be present also in the anticipated ERTS data.

Reservoir Accumulation. Water accumulation behind major dams has been repeatedly observed by meteorological satellites. Change in tone and pattern related to water accumulation behind the Aswan Dam has been observed by Nimbus I, II, and III satellites between 1964 and 1969.

When the Gemini IV photograph was taken in June 1965 (Fig. 15), the Aswan High Dam was beginning to fill, as is evident in the tributary canyons with water in them. In Figure 16, Lake Nasser, the name for the immense body of water backed up by the Aswan Dam, dominates the foreground of this view of Egypt photographed by Apollo IX astronauts in March of 1969. Nimbus satellite systems have recorded images of the Lake Nasser area since September 1964. The increase in lake size can be seen between the 1964 conditions (Fig. 17A) and 1969 (Fig. 17D) [27].

Repetitive observations of similar reservoir fill-ups would be more frequent during the initial phases and would decline to monthly and yearly monitoring after their completion.

Flooding and Drought. The Nimbus and ITOS television and infrared imaging sensors have the capacity to monitor surface moisture and extent of water bodies. The effects of a spring flood of the Ouachita River on ground water migrations and vegetation blooms have been detected by Nimbus 3 HRIR sensors (Fig. 18). The Apollo IX near-infrared image of the area (Fig. 19), taken March 9, 1969, shows this area at the height of the flood when about 165 mi$^2$ were inundated. From the analysis of the digitized Nimbus III HRIR grid-print reflectance maps[8] [14,18], it was concluded that this flood had more effect on the intensively cultivated area along the Mississippi River, with a lesser effect on the more forested highlands in the western half of the map. Weekly and monthly observations revealed the lingering effects of this flood on the

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8. Grid-print maps — Computer-produced maps of temperature or reflectance values.

ground water migrations, water table oscillations, and vegetation responses to the above-mentioned conditions, several months after the flood.

Drought conditions have also been observed by the Nimbus III HRIR daytime satellite sensors in the lower Mississippi Valley. Where severe drought conditions affected this area during the summer of 1969, a general increase in terrain reflectance is observed (Fig. 20). The moisture decrease, from May 22 to August 9, resulting from a decrease in rainfall, affected the vegetal cover (wilted vegetation, poor crop yield) and soil texture; the radiometer, in turn, integrated those changes as higher reflectances. Similarly, a reversal to a lower relative reflectance by September 12 was a response to moisture added to the ground from increased rainfall [13, 14, 18].

Vegetation Boundaries. In Figure 21 the reflectance changes observed in the three Nimbus III HRIR daytime images of Western Africa correlate roughly with the broad vegetation zones of the tropical forest, Savanna-Forest, and Savanna Grasslands that belt the West African Continent south of the Sahara Desert. These regional vegetation boundaries correspond to changes in soil moisture, as a response to seasonal meteorological conditions [13, 14]. Mapping of such dynamic features will be greatly enhanced by the availability of repeat satellite coverage, since the vegetation boundaries fluctuate latitudinally from season to season. This figure illustrates once more that conventional vegetation boundary maps are inadequate for the depiction of similar temporal events.

## Geographic and Geologic Applications

Map Revisions. Geographic maps of polar areas have been updated using the Nimbus satellite imagery [28]. Ice front locations in Antarctica have been revised [29]. Mount Siple was repositioned 2 deg west, and a mountain group in the Kohler Range was eliminated as it had been positioned differently by two different expeditions (Fig. 22). Nimbus I and II imagery has supplemented conventional data in the preparation of maps of portions of Tibet and China [30].

Differential reflectance effects of snow occasionally highlight previously nondiscernible ground features. Repetitive satellite observations are able to take advantage of this fact. A new vegetation boundary was suggested in Canada because the seasonal effects of snow highlighted the boundary between areas of less than 30 percent and more than 30 percent woodland cover [31]. Midwinter observations, with too much snow, obscured the boundary; whereas late spring observations had too little snow. The optimum observation period existed for only 2 months.

The aid of repetitive observations of snow cover in geologic mapping is illustrated in Figure 23. Through the analysis of a fresh snow pattern, photographed by the Nimbus I TV camera, a fault in the East Sayan Mountains of the U.S.S.R. was detected. The fact that a few weeks earlier or later this pattern would have been obscured by a lack of snow or too much of it reveals how unusual and unexpected the benefits may be from the analysis of satellite repetitive observation photographs.

Volcanic Activity. Cases of effusive volcanic activity have been recorded by orbital infrared systems, Kilauea and Etna by the Nimbus I satellite and Surtsey by the Nimbus 2 satellite. Surtsey is the best documented and appeared as a minute spot on more than eight separate orbits of the Nimbus HRIR between August 20 and October 30, 1966 (Fig. 24). Calculations indicate that only about 3 percent of Surtsey's total thermal energy left the earth's atmosphere as radiant energy [32]. Nevertheless, the repeated detection of Surtsey demonstrates that radiation from effusive volcanic events of similar magnitude can be detected and monitored from earth orbit with appropriate systems and repetitive looks over an area.

In another instance, a plume resulting from the eruption of the Beerenberg Volcano on Jan Mayen Island was observed by the Nimbus IV IDCS camera and daytime HRIR system, beginning on September 21, 1970 (Fig. 25). This observation demonstrates once more the significance of frequent repetitive satellite observations in improving our understanding of natural processes of the earth and atmosphere [33].

The Nimbus IV satellite relayed the temperature of steam emitted from the snowcapped Mount Rainier volcano in Washington [34]. This is the first time that volcanic activity information had been transmitted on a daily basis by a satellite. In the future, pictorial information may accompany data from similar Interrogation, Recording and Location Systems (IRLS).

Playa Changes. Western U.S. playas have been examined from space and evaluated as potential aircraft landing sites. Changes in surface moisture conditions would affect their availability as landing sites. Repetitive observations correlated with ground measurements could establish a basis for satellite determination of the daily activity of these playas as landing sites. Research along these lines has shown the value of satellite pictures although improved resolutions are required for more detailed information.

Figure 26 is a Nimbus I AVCS photograph taken over northwestern Nevada. It shows a variety of playa surface conditions, ranging from hard, dry crusts (locations 2, 3, 6, 7, 16 and 19) to soft, dry, friable surfaces (locations 5, 8, 10, 14 and 15). Neal [35] concludes that the utility of Nimbus images in playa studies is limited, but they nevertheless contain usable information when used in conjunction with higher resolution photography, such as that from the Gemini mission (Fig. 27). Consequently, repetitive high-resolution imagery from the ERTS will allow continuous monitoring of playa surfaces on an 18-day basis, at least when the cloud cover is absent.

Delta Sedimentation. Delta sedimentation plumes have been observed on Nimbus I imagery at the mouth of the Colorado River in the Gulf of California and at the mouth of the Tigris-Euphrates Rivers in the Persian Gulf (Fig. 28). ATS III has observed this feature off the mouth of the Amazon River (Fig. 29). Numerous examples of coastal and inland lake deltaic sedimentation have also been photographed by the Gemini and Apollo (Fig. 30) astronauts. Sedimentation is an extremely dynamic process and, in order to be monitored effectively, should be observed on a weekly and, at times, even on a daily basis. Presently available daily coverage from meteorological satellites is too poor for such purposes. The ERTS program will improve the situation somewhat; however, more than biweekly coverage is necessary for the monitoring of such temporal terrestrial events, as sedimentation, crop maturation, or volcanic eruptions.

## Miscellaneous Observations

Duststorms. Sahara Desert duststorms have been observed daily on Nimbus satellite imagery (Fig. 31). No intensive investigation has yet been performed to determine the frequency at which these phenomena should be observed, or the quantitative information that could be obtained from the Nimbus imagery. The ATS III photographed a similar duststorm a year earlier (1969) over the same region, monitored on an hourly basis. To date, however, eolian processes of erosion, deposition, and associated landforms have not been studied with the aid of Nimbus or ATS data.

Ship Plumes. Ship condensation trails have bee observed on satellite imagery and documented with ground observations [36]. These features, where and when they exist, can be charted. The present civilian utility of this information is not very great, although this does have implications for monitoring of contrail persistence from the future supersonic air transports in relation to atmospheric pollution.

The long, thin, anomalous cloud bands in the Nimbus III IDCS pictures, in Figure 32, are most probably ship plumes or "trails." Daily and weekly observations of these features from space would greatly enhance the inventorying of oceanic transport activities and ship-traffic routing. Ship plumes have also been photographed by Gemini and Apollo astronauts, and recorded by ITOS and ATS systems.

Forest and Brush Fires. Smoke from large fires in Alaska has been observed on ESSA satellite imagery [37]. Figure 33, from the Nimbus IV IDCS, shows smoke plumes from major brush fires in southern California. Figure 34 shows similar fires over the mouth of the Zambezi River at Mozambique, East Africa, photographed by Apollo VII astronauts.

Even though forest fires have been photographed from space, present poor resolution of the meteorological satellite sensors and nonrepetitive observations by the Gemini and Apollo astronauts preclude operational monitoring of the effects of such fires on resources economics and atmospheric pollution.

## Conclusion

The list of temporal terrestrial features presented in this paper and summarized in Table 1, as observed from space, is not exhaustive. The need for repetitive observations of dynamic features is, however, self-evident if we ever hope to fully understand the changes affecting our broad-scale, repetitive views of the earth from future space missions, such as ERTS, for example, will be especially useful for a wide variety of regional inventory and planning programs. Such inventories may then be used to identify areas of change so that acquisition of more precise information by aircraft or ground methods could be planned.

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# TABLE 1. FREQUENCY OF OBSERVATIONS PRESENTLY POSSIBLE AND NECESSARY FOR THE DETECTION OF TEMPORAL TERRESTRIAL FEATURES. ALL THESE CHANGES HAVE BEEN OBSERVED ON ORBITING SPACE IMAGERY, AND MANY HAVE BEEN REPEATEDLY MONITORED BY THE METEOROLOGICAL SATELLITES.

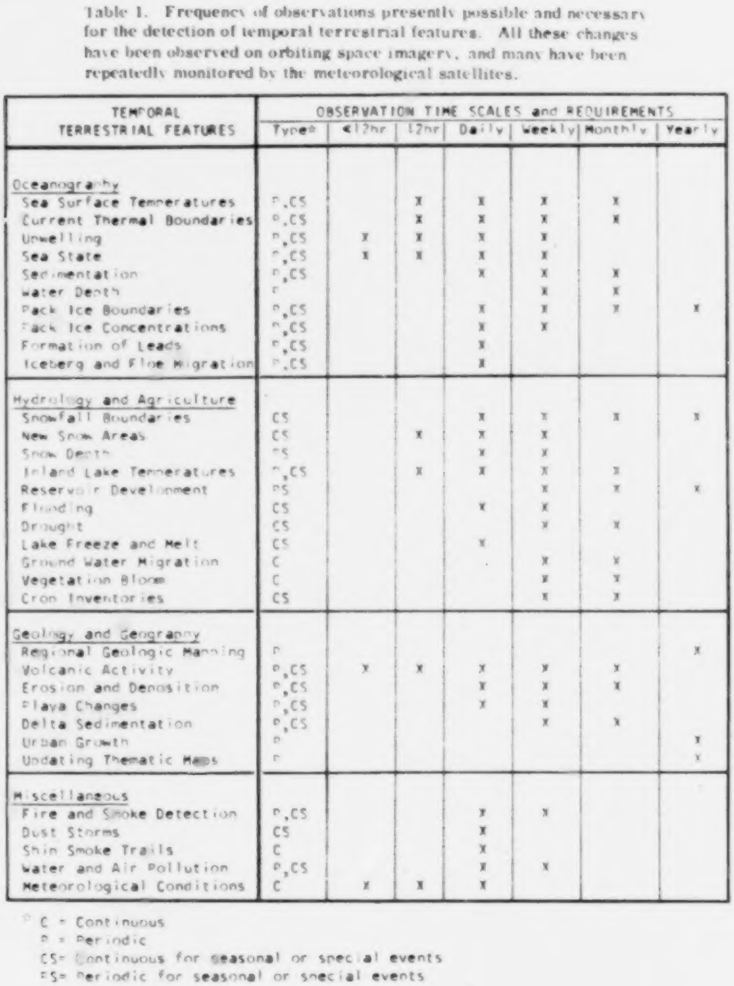
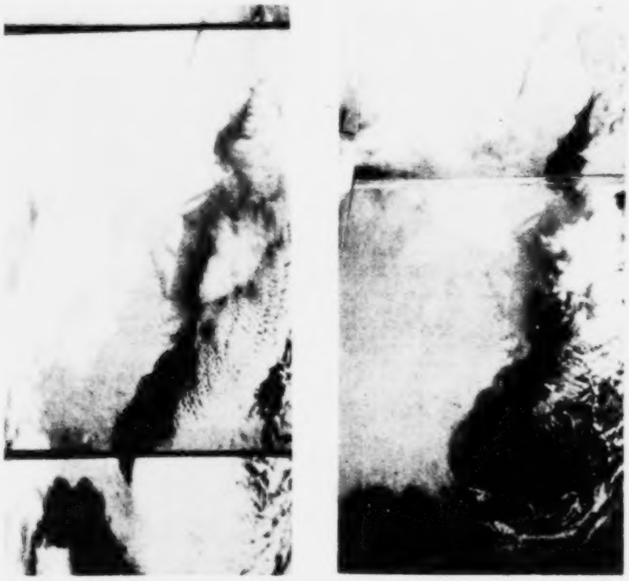


Table 1. Frequency of observations presently possible and necessary for the detection of temporal terrestrial features. All these changes have been observed on orbiting space imagery, and many have been repeatedly monitored by the meteorological satellites.

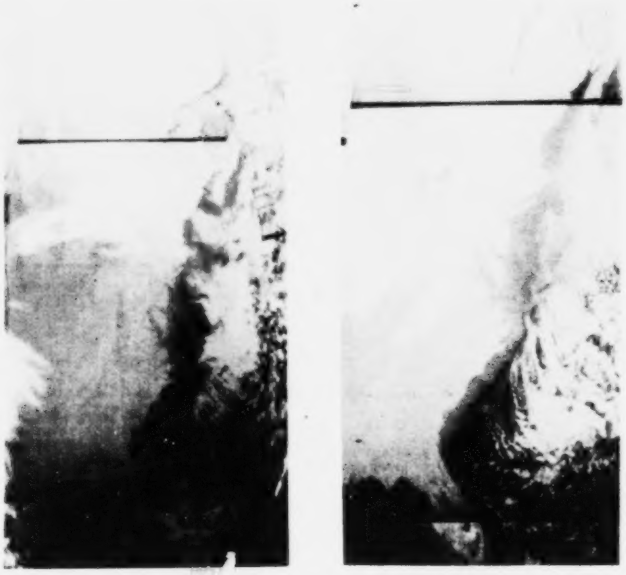
| TEMPORAL TERRESTRIAL FEATURES | OBSERVATION TIME SCALES and REQUIREMENTS | | | | | | |
|---|---|---|---|---|---|---|---|
| | Type* | <12hr | 12hr | Daily | Weekly | Monthly | Yearly |
| Oceanography | | | | | | | |
| Sea Surface Temperatures | P,CS | | X | X | X | X | |
| Current Thermal Boundaries | P,CS | | X | X | X | X | |
| Upwelling | P,CS | X | X | X | X | | |
| Sea State | P,CS | X | X | X | X | | |
| Sedimentation | P,CS | | | X | X | X | |
| Water Depth | P | | | | X | X | |
| Pack Ice Boundaries | P,CS | | | X | X | X | X |
| Pack Ice Concentrations | P,CS | | | X | X | | |
| Formation of Leads | P,CS | | | X | | | |
| Iceberg and Floe Migration | P,CS | | | X | | | |
| Hydrology and Agriculture | | | | | | | |
| Snowfall Boundaries | CS | | | X | X | X | X |
| New Snow Areas | CS | | X | X | X | | |
| Snow Depth | PS | | | X | X | | |
| Inland Lake Temperatures | P,CS | | X | X | X | X | |
| Reservoir Development | PS | | | | X | X | X |
| Flooding | CS | | | X | X | | |
| Drought | CS | | | | X | X | |
| Lake Freeze and Melt | CS | | | X | | | |
| Ground Water Migration | C | | | | X | X | |
| Vegetation Bloom | C | | | | X | X | |
| Crop Inventories | CS | | | | X | X | |
| Geology and Geography | | | | | | | |
| Regional Geologic Mapping | P | | | | | | X |
| Volcanic Activity | P,CS | X | X | X | X | X | |
| Erosion and Deposition | P,CS | | | X | X | X | |
| Playa Changes | P,CS | | | X | X | | |
| Delta Sedimentation | P,CS | | | | X | X | |
| Urban Growth | P | | | | | | X |
| Updating Thematic Maps | P | | | | | | X |
| Miscellaneous | | | | | | | |
| Fire and Smoke Detection | P,CS | | | X | X | | |
| Dust Storms | CS | | | X | | | |
| Ship Smoke Trails | C | | | X | | | |
| Water and Air Pollution | P,CS | | | X | X | | |
| Meteorological Conditions | C | X | X | X | | | |

* C = Continuous
P = Periodic
CS= Continuous for seasonal or special events
PS= Periodic for seasonal or special events



NIMBUS III
4 FEBRUARY 1970

NIMBUS III
22 FEBRUARY 1970



ITOS I
22 FEBRUARY 1970

NIMBUS III
26 FEBRUARY 1970

Figure 1. Gulf Stream thermal boundary. These HRIR pictures show the sharp thermal boundary along the north wall of the Gulf Stream. Changes in boundary shape and position are evident. Black picture tones identify the warmest areas. White tones identify the coldest. These pictures were recorded at Goddard Space Flight Center, Greenbelt, Maryland, on an inexpensive ground station (commercially available for about $5000) especially designed for the direct reception weather satellite pictures.

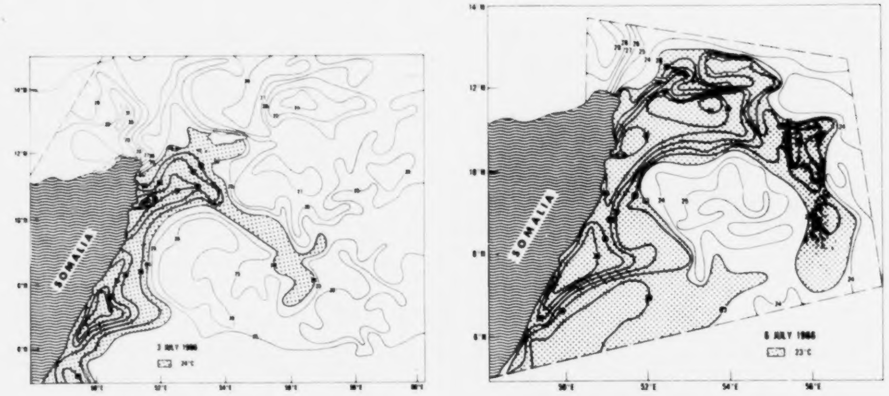

SOMALIA
3 JULY 1966
24°C
SOMALIA
14°N
12°N
10°N
8°N
6°N
6 JULY 1966
23°C
50°E
52°E
54°E
56°E

Figure 2. Upwelling changes near the Samolia coast between July 3 and 6, 1966. These two maps show the changing thermal pattern as recorded by the Nimbus II HRIR at the beginning of upwelling near the Samolia coast. The development of the clockwise circulation pattern was correlated with the bloom of phytoplankton.

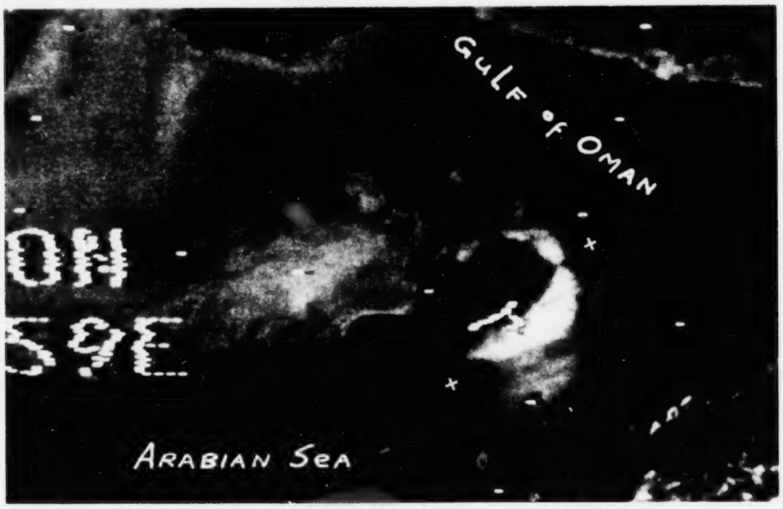

GULF OF OMAN
ARABIAN SEA
0N
59E

Figure 3. Sunlight pattern with adjacent anomalous dark spots. This is the central portion of a Nimbus IV IDCS picture taken off the southeast coast of Saudi Arabia on April 15, 1970. The two white x's mark the dark spots which are believed to be areas of calm water and possible upwelling. Southeast Iran is in the upper right corner. (All Nimbus pictures in this report were furnished by the NASA Nimbus Project, Goddard Space Flight Center, Greenbelt, Maryland.)

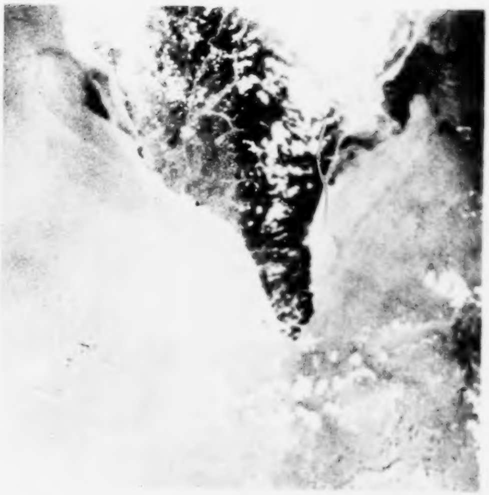


Figure 4. A Gemini X view of ocean surface conditions south of Taiwan (NASA photo).

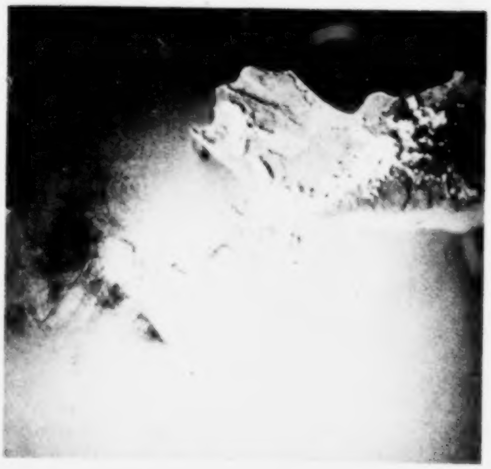


Figure 5. The sun blazed on Socotra Island and the Indian Ocean for this photo. Left of the sunglint, between the big island and smaller ones called the Brothers, a slicklike eddy is darkly outlined. Note the fine, white horizontal line below Socotra. Waves rolling over an undersea shelf 10 miles offshore may have produced it [8] (NASA photo).

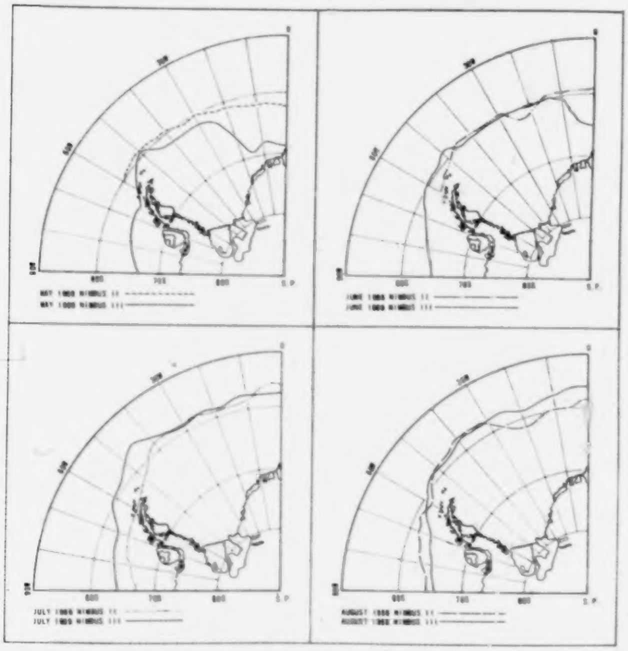
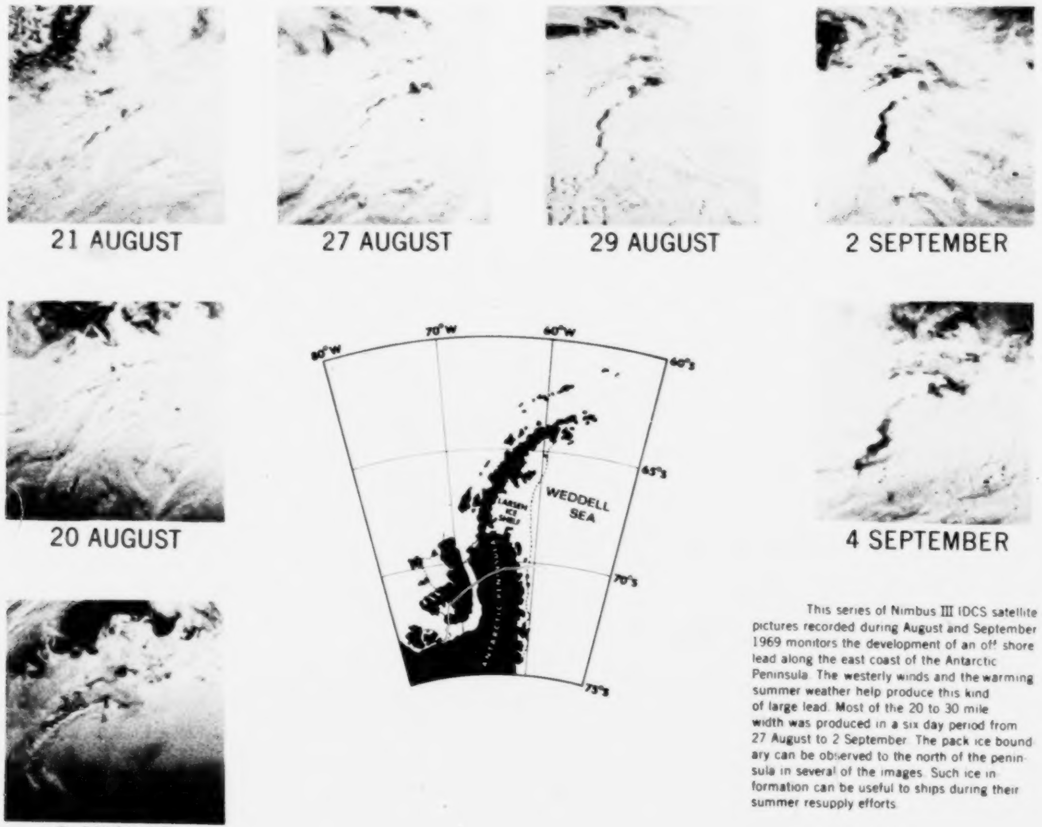


Figure 6. Monthly and yearly fluctuations in Antartic pack ice boundaries derived from Nimbus satellite data.


80°W
70°W
60°W
60°S
65°S
70°S
75°S
LARSEN ICE SHELF
WEDDELL SEA
ANTARCTIC PENINSULA

21 AUGUST

27 AUGUST

29 AUGUST

2 SEPTEMBER

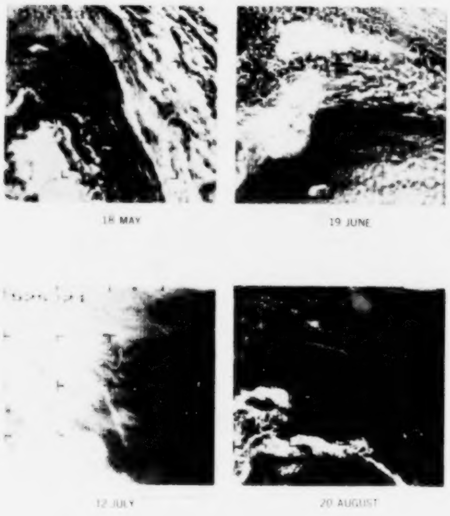
20 AUGUST

4 SEPTEMBER

9 AUGUST

This series of Nimbus III IDCS satellite pictures recorded during August and September 1969 monitors the development of an off shore lead along the east coast of the Antarctic Peninsula. The westerly winds and the warming summer weather help produce this kind of large lead. Most of the 20 to 30 mile width was produced in a six day period from 27 August to 2 September. The pack ice boundary can be observed to the north of the peninsula in several of the images. Such ice information can be useful to ships during their summer resupply efforts.

Figure 7. Development of an offshore lead in Antarctica.



18 MAY

19 JUNE

12 JULY

20 AUGUST

Figure 8. Repetitive observations of a tabular iceberg in the Antarctic Ocean. Nimbus II pictures.

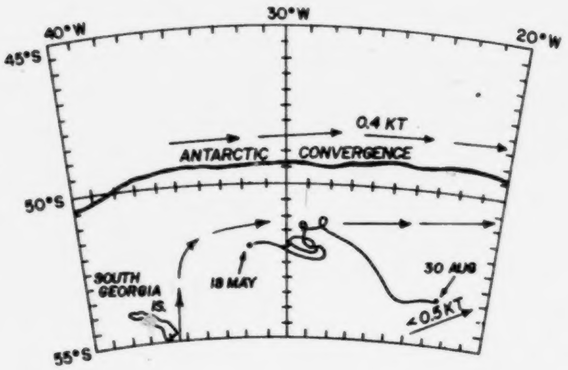
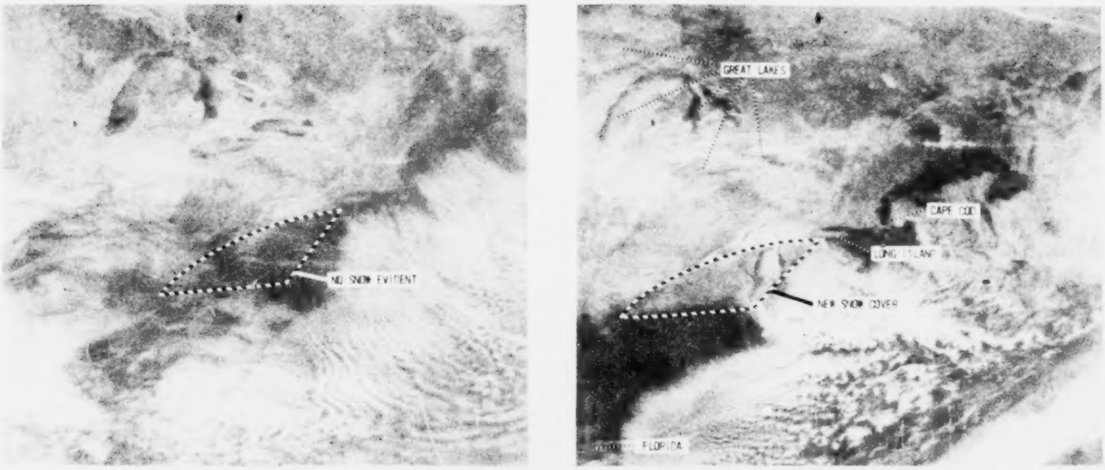

30°W
40°W
20°W
45°S
50°S
55°S
0.4 KT
ANTARCTIC CONVERGENCE
SOUTH GEORGIA IS.
18 MAY
30 AUG
<0.5KT

Figure 9. Observed track, from May 18 to August 30, 1966, of the tabular iceberg viewed in Figure 8.


NO SNOW EVIDENT
GREAT LAKES
CAPE COD
LONG ISLAND
NEW SNOW COVER
FLORIDA

NIMBUS III DIRECT READOUT IDCS ORBIT 3571 5 JANUARY 1970
EASTERN UNITED STATES WITH SNOW COVER

NIMBUS III DIRECT READOUT IDCS ORBIT 3611 8 JANUARY 1970
EASTERN UNITED STATES WITH SNOW COVER

Figure 10. Three-day change in snow pattern. A January 7, 1970, snowstorm dumped new snow in Delaware, Maryland, Virginia, and other eastern areas which had previous snow on the ground.

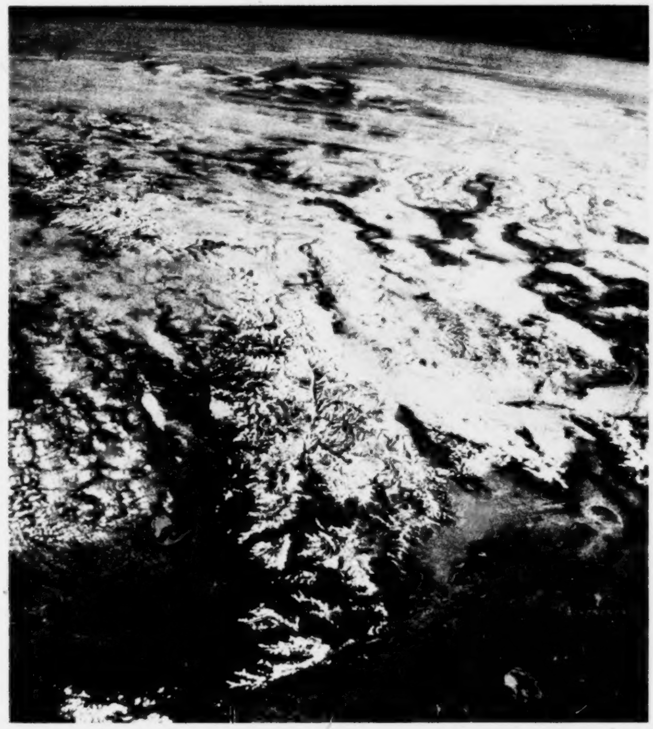


Figure 11. Apollo IX photograph (March 1969) showing mountain snow cover in southern Sierras region, U.S. The ground resolution in this photograph is of the order of that proposed for future Earth Resources Satellites Systems (NASA photo).

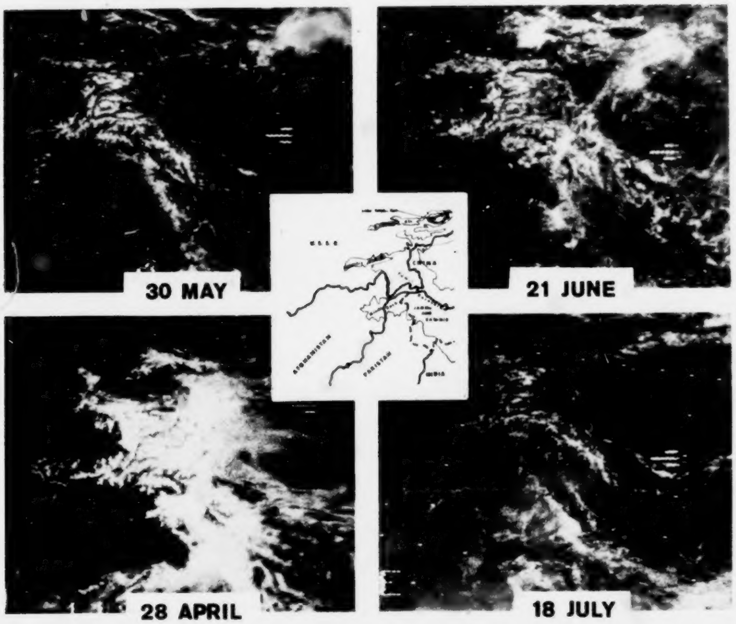
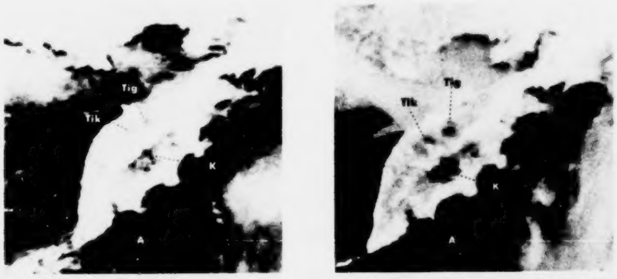
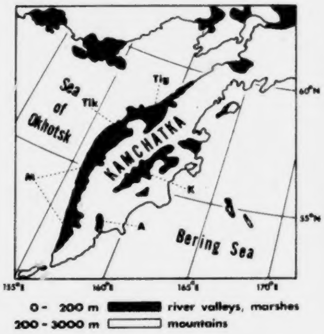

30 MAY
21 JUNE
28 APRIL
18 JULY

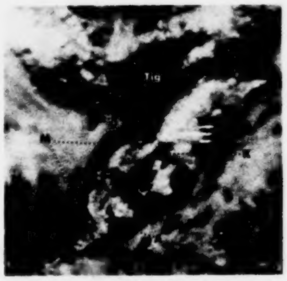
Figure 12. Monthly changes in snow cover in the Hindu Kush and Himalaya Mountains. This temporal sequence of Nimbus III IDCS pictures suggests the utility of a satellite platform to monitor seasonal changes in snow cover. The time and amount of snowmelt is an important input for flood and irrigation planning.


Tig
Tik
K
A
Tig
Tik
K
A

22 April 1970 - Snow melt has begun in the Kamchatka (K), Avacha (A), Tikhaya (Tik), and Tigil (Tig) river valleys.

27 April 1970 - Further snow melt in these river valleys is evident. Note also, overall peninsula reflectances have decreased.


Sea of Okhotsk
Tig
Tik
KAMCHATKA
M
K
A
Bering Sea
60°N
55°N
155°E
160°E
165°E
170°E
0 - 200 m
river valleys, marshes
200 - 3000 m
mountains



27 May 1970 - All river valleys (K, A, Tik, Tig) and marshland (M) snow cover has melted.

Figure 13. Snowmelt surveillance, Kamchatka, U.S.S.R., Nimbus IV IDCS.

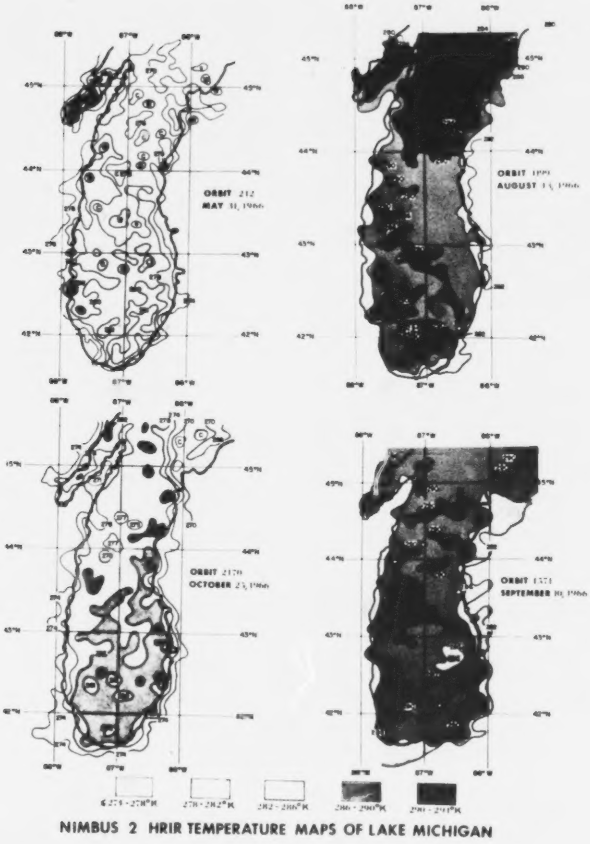

ORBIT 212
MAY 31, 1966
ORBIT
AUGUST
ORBIT 2170
OCTOBER 23, 1966
ORBIT
SEPTEMBER
45°N
44°N
43°N
42°N
88°W
87°W
86°W
278 - 282°K
282 - 286°K
286 - 290°K
NIMBUS 2 HRIR TEMPERATURE MAPS OF LAKE MICHIGAN

Figure 14. Nimbus II HRIR temperature maps of Lake Michigan derived from digitized data.

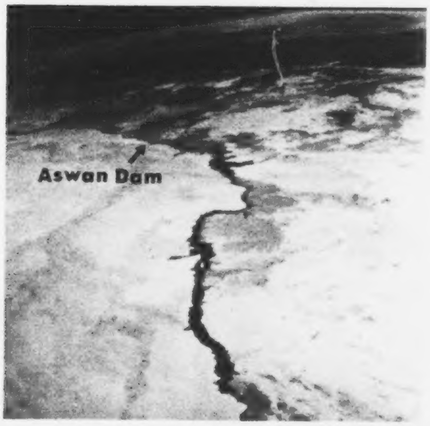


Figure 15. Gemini IV photograph of the Aswan High Dam during the initial stages of its filling. The dam is at the top. Part of the area in the center is now flooded by the reservoir (NASA photo).

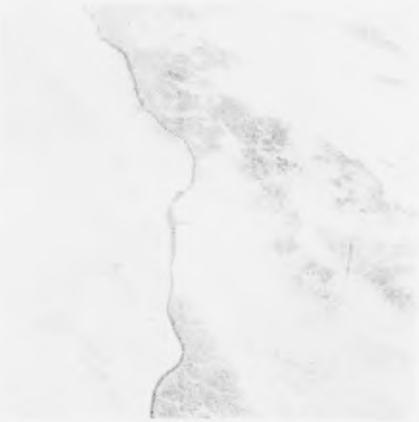


Figure 16. Lake Nasser, a long, immense body of water backed up by the Aswan Dam, dominates the foreground of this view of Egypt. The Red Sea is on the horizon (NASA photo).

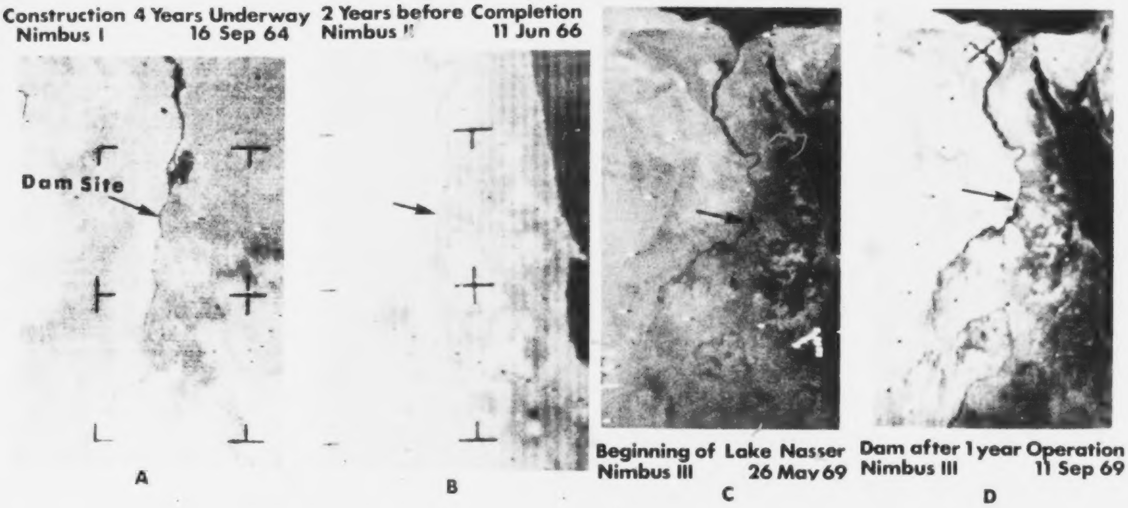

Construction 4 Years Underway
Nimbus I 16 Sep 64
Dam Site
A
2 Years before Completion
Nimbus II 11 Jun 66
B
Beginning of Lake Nasser
Nimbus III 26 May 69
C
Dam after 1 year Operation
Nimbus III 11 Sep 69
D

Figure 17. Growth of the Aswan High Dam monitored by Nimbus satellite cameras.

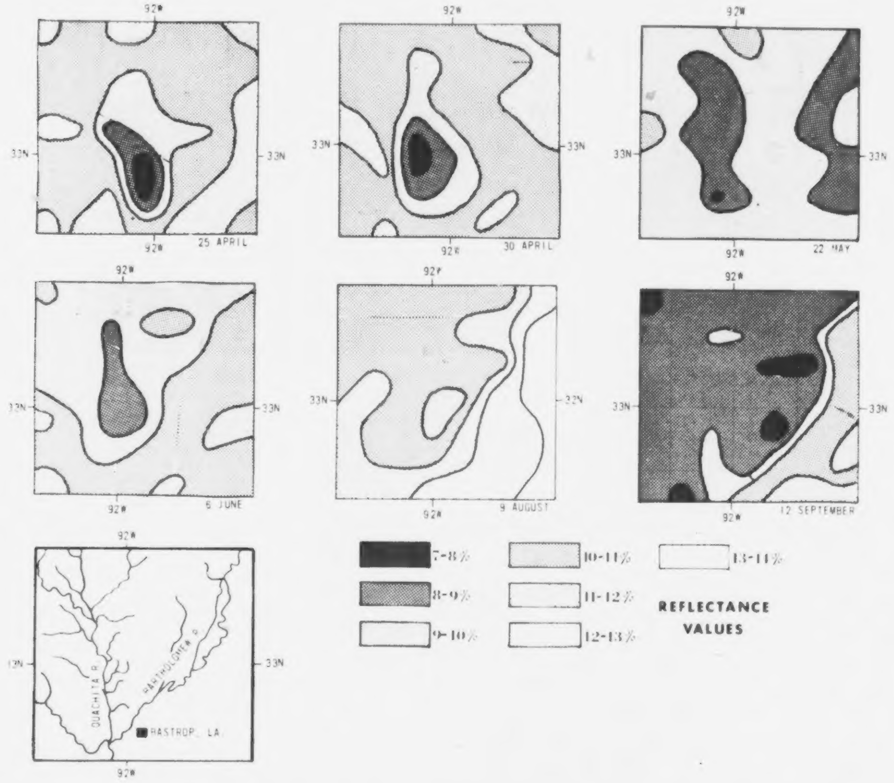

92W
33N
25 APRIL
30 APRIL
22 MAY
6 JUNE
9 AUGUST
12 SEPTEMBER
OUACHITA R.
BARTHOLOMEW R.
BASTROP, LA.
7-8%
8-9%
9-10%
10-11%
11-12%
12-13%
13-14%
REFLECTANCE VALUES

Figure 18. Nimbus III daytime HRIR temporal sequence of reflectance values derived from computer-produced grid print maps. The area is along the Ouachita River at the Louisiana-Arkansas border. Changes in reflectance values and pattern along the Ouachita correlate with lingering effects of an early spring flood. Some of the other patterns correlate with soil and vegetation patterns.

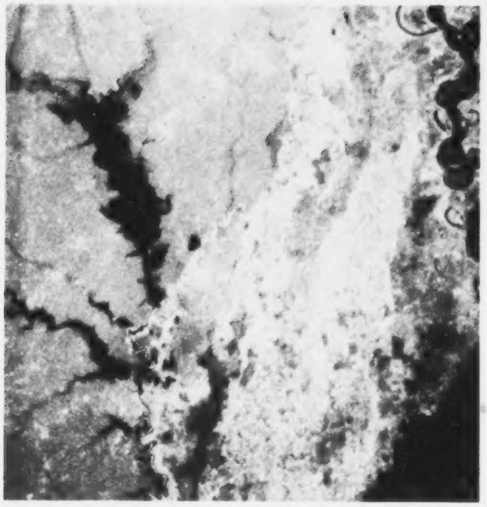
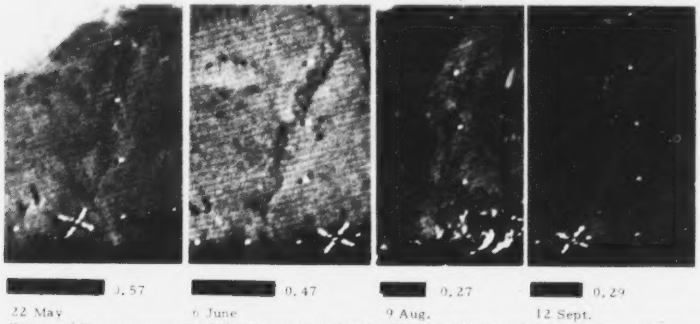
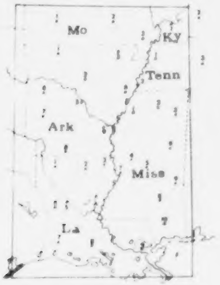


Figure 19. Apollo IX photograph of the lower Mississippi Valley taken on March 9, 1969. The flooded Ouachita River is in the upper left-hand portion of the picture. The highly cultivated flood plains of the Mississippi River occupy the right-hand portion of the photograph (NASA photo).



Horizontal bars represent rainfall averages in inches for the week prior to image acquisition. May 22 — rainfall of 0.5 to 2 in. on May 18; June 6 — rainfall 0.2 to 1.2 in. in Louisiana and Mississippi on June 2. Light and scattered rainfall elsewhere since May 22; August 9 — almost no rainfall since July 28; September 12 — generally heavy rainfall 1 - 12 September. No rainfall from September 9 - 12.



ARKANSAS
1. Harrison
2. Greers Ferry
3. Walnut Ridge
4. Blue Mts. Dam
5. Little Rock
6. Forrest City
7. Narrows Dam
8. El Dorado
9. Dumas

KENTUCKY
1. Paducah
2. Madisonville

LOUISIANA
1. Minden
2. Calhoun Exp. Sta.
3. Epps 5 W
4. Leesville
5. Alexandria
6. Baton Rouge
7. Lake Charles
8. Lafayette
9. New Orleans

MISSISSIPPI
1. Clarksdale
2. University
3. Tupelo
4. Yazoo City
5. Canton
6. Louisville
7. Vicksburg
8. Collins
9. Meridian
10. Wiggins

MISSOURI
1. Springfield
2. Ellington
3. Malden

TENNESSEE
1. Dyersburg
2. Memphis
3. Centerville

Gauging stations from which rainfall information was collected.

Figure 20. The varying tonal changes in the Mississippi River Valley illustrated here correspond to solar reflectance recorded by the Nimbus III radiometer (daytime HRIR) in the 0.7 to 1.3 $\mu$m band.

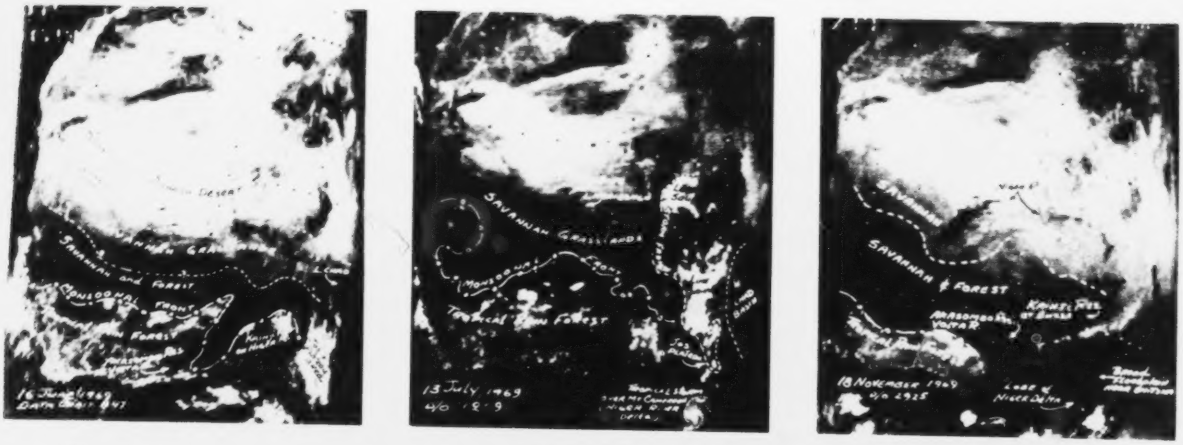
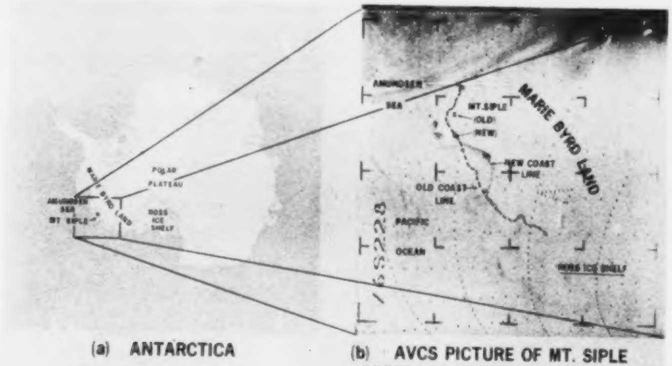

Sahara Desert
Savannah Grassland
Savannah and Forest
Monsoonal Front
Rain Forest
Kainji
16 June 1969
Savannah Grasslands
Monsoonal Front
Tropical Rain Forest
13 July 1969
Savannah
Savannah & Forest
Akosombo
Volta R.
Kainji
18 November 1969
Lake of Niger Delta

Figure 21. Temporal sequence of Nimbus III (day) photofacsimile prints showing western Africa. June 16 - advancing wet season for tropical West Africa; clouds are moving inland from the Gulf of Guinea. July 13 - clouds move inland to approximately 15 deg N latitude; storm gyre over Niger River delta; frontal storms over Jos Plateau and northern Nigeria (above Komadiya-Yube and Sokota River Basins). November 18 - dry season for tropical West Africa. Dust and haze of the harmattan to altitudes of 8000-12 000 ft over the Niger River Basin and nothern Nigeria.


AMUNDSEN SEA
MT SIPLE
MARIE BYRD LAND
POLAR PLATEAU
ROSS ICE SHELF
AMUNDSEN SEA
MT. SIPLE
(OLD)
(NEW)
MARIE BYRD LAND
NEW COAST LINE
OLD COAST LINE
PACIFIC OCEAN
ROSS ICE SHELF
165228

(a) ANTARCTICA

(b) AVCS PICTURE OF MT. SIPLE ORBIT 183/184 9 SEPTEMBER 1964

Figure 22. Antarctic map revisions derived from a Nimbus IV picture, recorded on September 9, 1964.

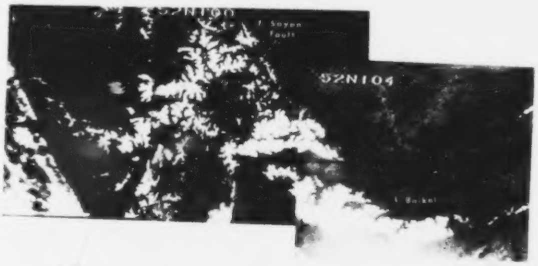

52N104
L. Baikal

Figure 23. Nimbus I view of the Sayan Mountains and vicinity, U.S.S.R.

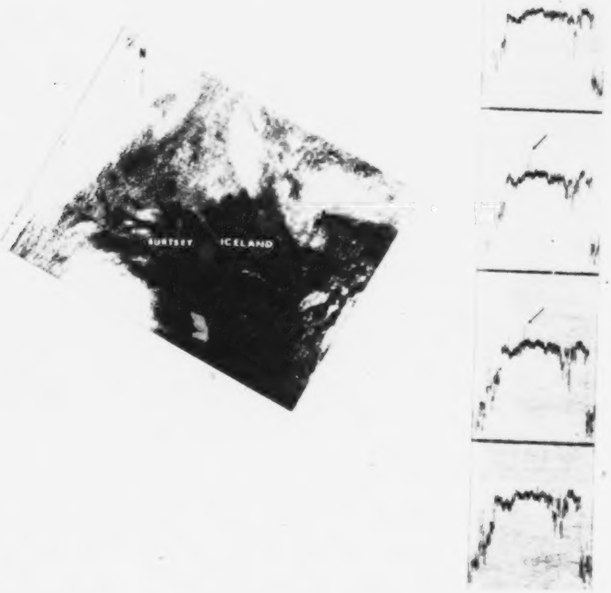

SURTSEY
ICELAND

Figure 24. Nimbus II HRIR photofacsimile of Surtsey Volcano observed on September 8, 1966, off the southwestern coast of Iceland. The volcanic eruption shows up as a warm (high) spike on two of the four consecutive analog traces across the Surtsey area.

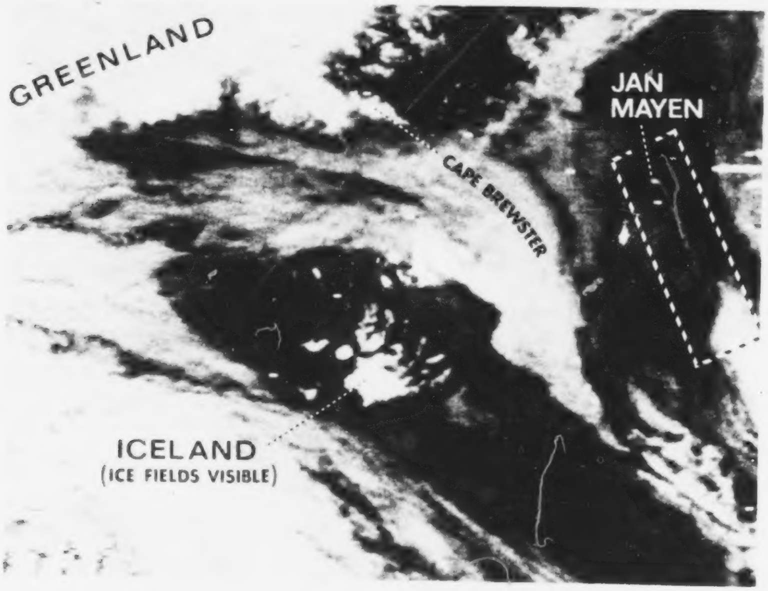

GREENLAND
JAN MAYEN
CAPE BREWSTER
ICELAND
(ICE FIELDS VISIBLE)

Figure 25. Ash Plume from Beerenberg Volcano. This new eruption of the Beerenberg Volcano on Jan Mayen Island was first observed on the night of September 20, 1970. By noon on September 21, when this Nimbus IV IDCS picture was taken, the ash plume (within the rectangular area) extended more than 200 mi to the southeast.

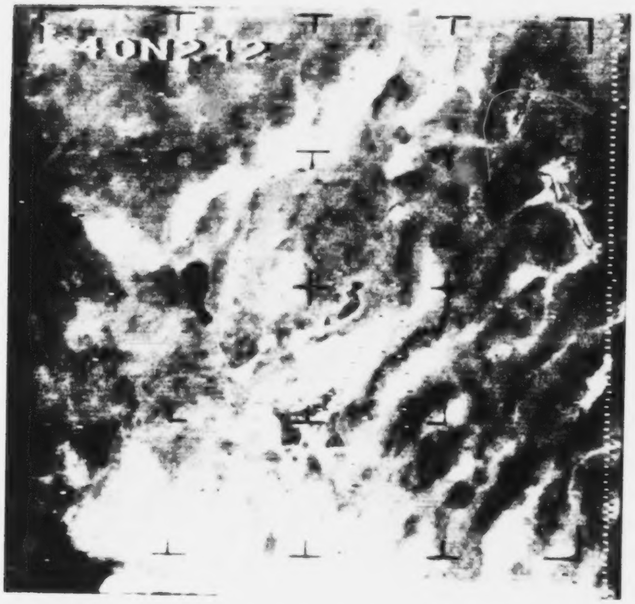


Figure 26. Nimbus I AVCS image, Northwestern Nevada, September 17, 1964. Good contrast separation between lake beds (white and light gray), alluvium (intermediate gray), forested mountains (dark gray), and lakes (black) is apparent.

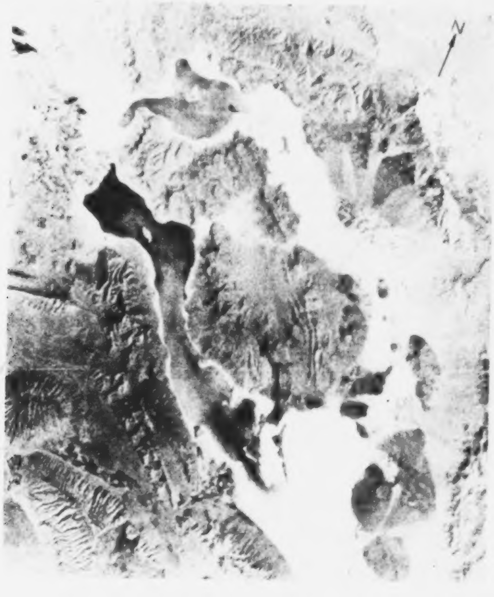


Figure 27. Gemini V photograph (late August 1965) of Southern Iran. Tashk and Bakhtigam Salt Lakes are clearly delineated (NASA photo).

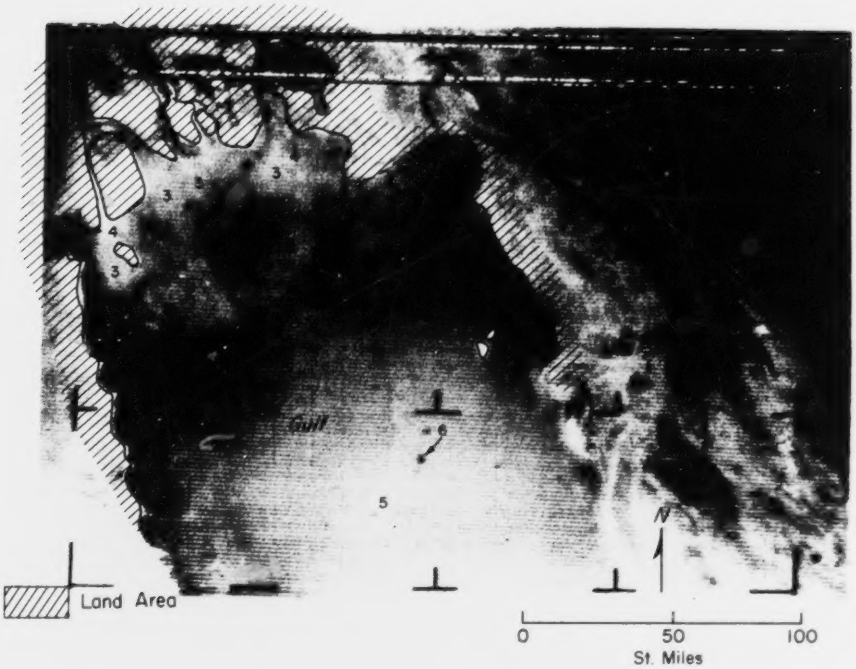


Figure 28. Nimbus I AVCS photograph of the Persian Gulf and the Tigris-Euphrates River Delta. Sedimentation plumes, submerged channels, and other features are identified.

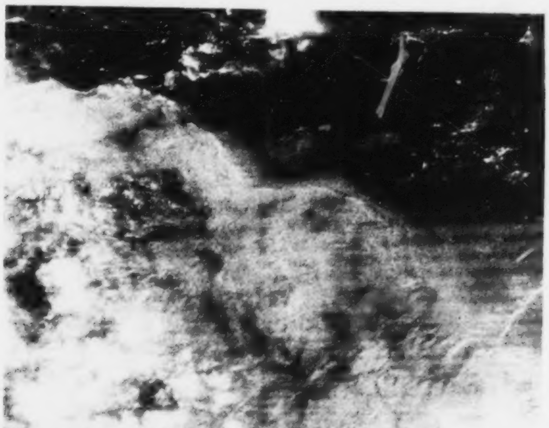


Figure 29. The ATS III view of the Southern Hemisphere. Every 20 min a photograph is taken by the ATS camera, and when the Brazilian coast is cloud free, sedimentation by the Amazon River may be observed on an hourly basis (NASA photo).

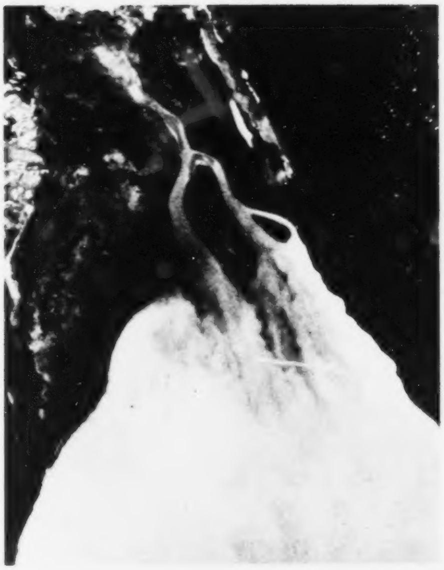


Figure 30. An Apollo IX view of the Colorado River's entrance to the Gulf of California. This is a black and white rendition of a color infráred picture of its delta and sediment plumes (NASA photo).

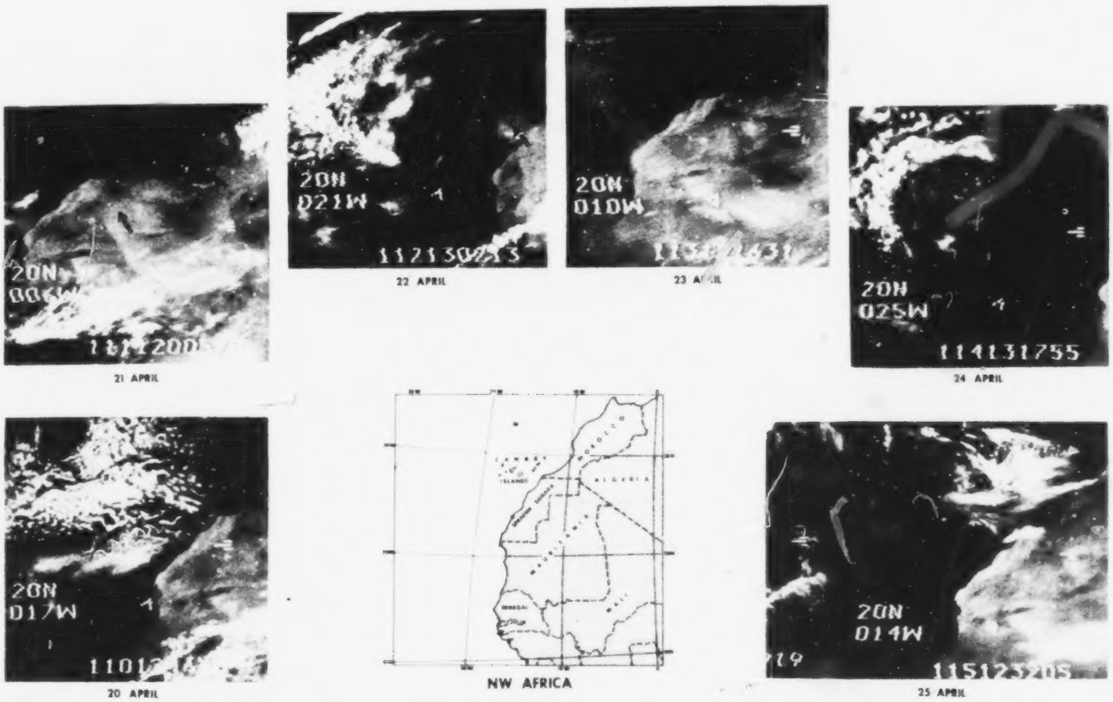
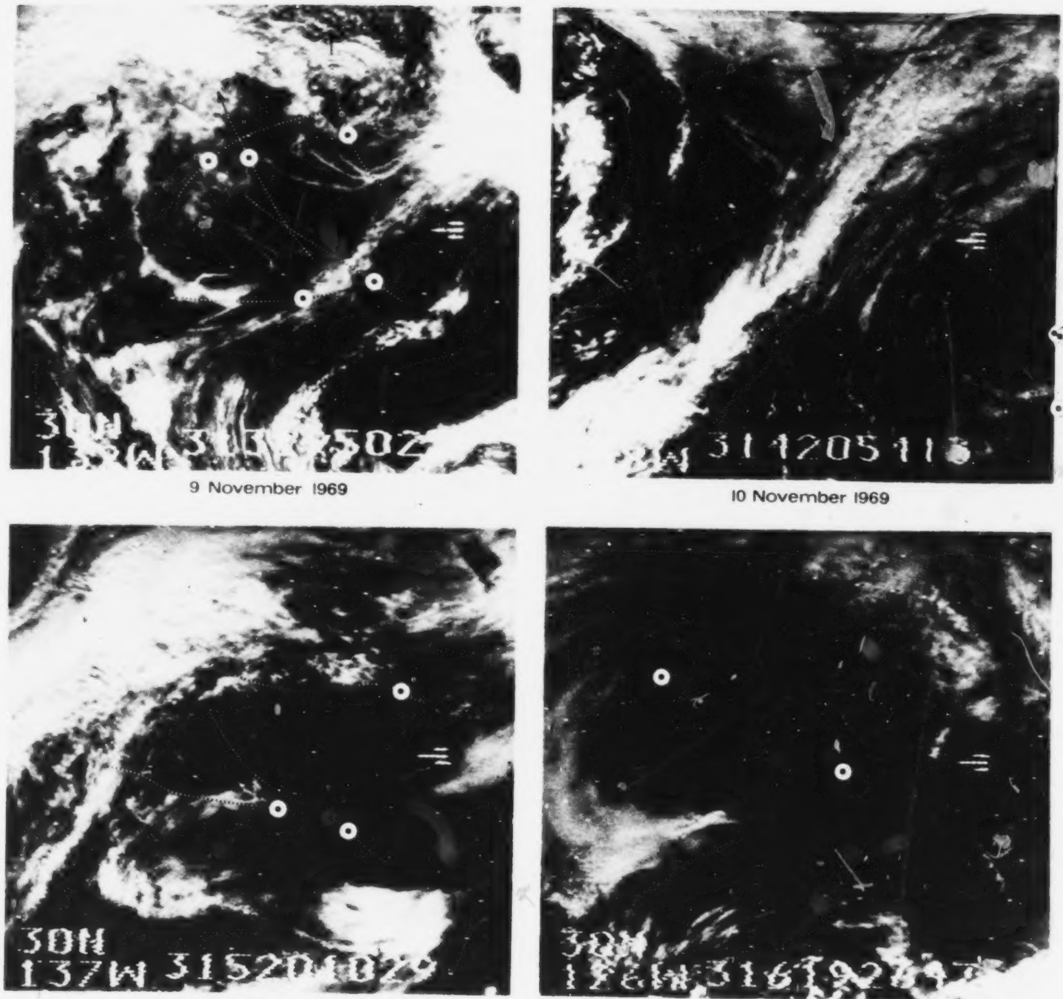

20N
021W
22 APRIL
20N
010W
23 APRIL
20N
006W
21 APRIL
20N
025W
114131755
24 APRIL
20N
017W
20 APRIL
CANARY ISLANDS
MOROCCO
ALGERIA
SENEGAL
MALI
NW AFRICA
20N
014W
25 APRIL

Figure 31. Nimbus IV IDCS monitors 1970 Sahara dust storm.



9 November 1969

10 November 1969

11 November 1969

12 November 1969

Figure 32. Nimbus III IDCS observations of ship plumes. The long, thin, anomalous cloud bands are probably ship plumes.

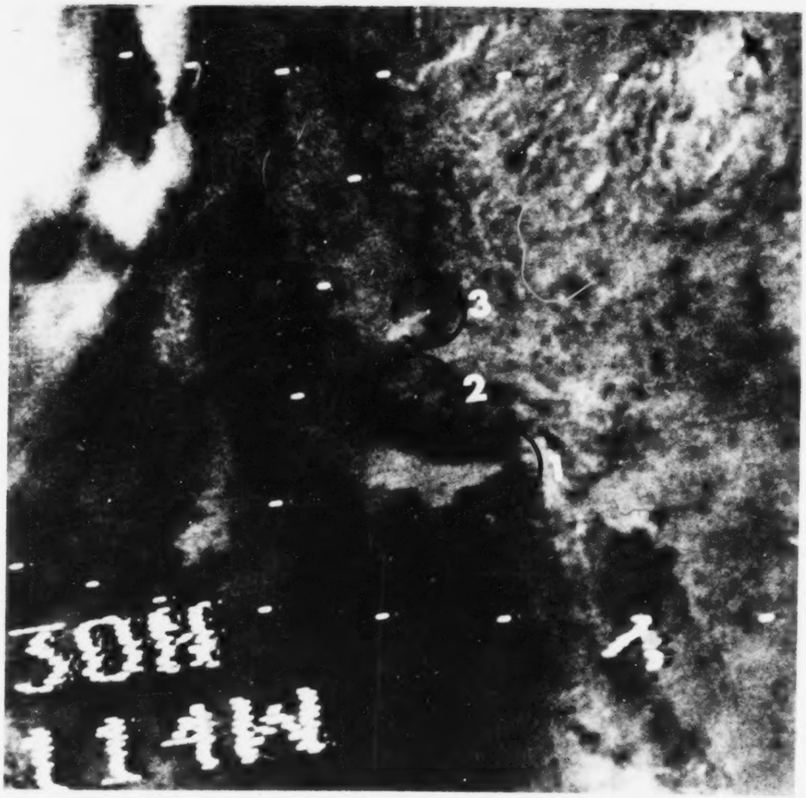


Figure 33. Southern California brush fire smoke plumes. This central portion of a Nimbus IV satellite IDCS picture taken on September 27, 1970, recorded smoke plumes from five of the major brush fires in Southern California. Plume locations are: 1. San Diego — 140 000 acres burning (1 plume); 2. Los Angeles — 105 000 acres burned (3 plumes); 3. Sequoia National Forest — 5000 acres burning (1 plume). (For reference: the Great Salt Lake is in upper right and Salton Sea is just above 1.)

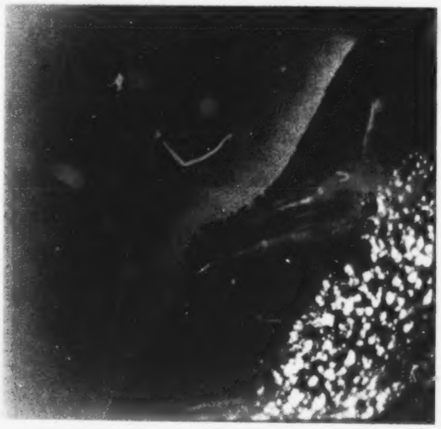


Figure 34. The mouth of the Zambezi River at Mozambique, East Africa. The light arrowlike streaks over the land are smoke and the hues off the shore are produced by sediment (NASA photo).

# INTERDISCIPLINARY APPLICATIONS AND INTERPRETATIONS OF REMOTELY SENSED DATA

By G. W. Petersen and G. J. McMurtry
Pennsylvania State University

## Abstract

Energy coming to the earth from the sun is reflected, scattered, or absorbed, and then radiated in the form of electromagnetic waves by objects on the earth. The wavelength of reflected or radiated energy is dependent upon the physical and chemical properties of the object. Modern instruments are capable of sensing and measuring this energy without being in physical contact with the object. Remote sensing can be accomplished from both aircraft and spacecraft, with each having distinct advantages. An interdisciplinary group at Pennsylvania State University is investigating the use of remote sensing for the inventory of natural resources and land use, determination of pollution sources and damage, and analysis of geologic structure and terrain. The geographical area of primary interest is the Susquehanna River Basin.

## Introduction to Remote Sensing

All energy coming to the earth is produced by the sun. This energy is either reflected, scattered, or absorbed, and then radiated as electromagnetic waves by objects on the earth. Because these objects differ in their physical and chemical properties, the wavelength of energy they radiate or reflect may vary from very short, such as X-rays, to very long, such as radio waves. Modern instruments are capable of sensing and measuring energy reflected or emitted at various wavelengths of the electromagnetic spectrum. An example is the camera with color film that senses energy reflected only in the visible portion of the electromagnetic spectrum. These devices acquire information about objects that are not in physical contact with these data gathering devices. The technology involved with these types of data gathering or imaging devices is thus called remote sensing [1, 2]. The most common types of airborne remote sensing instruments are as follows:

1. Conventional Aerial Camera. Cameras photographically record the radiation reflected in the visible portion of the electromagnetic spectrum. By using various filters, the visible spectrum can be subdivided so that only portions of the electromagnetic spectrum are recorded on film. Energy reflected in only the blue portion of the electromagnetic spectrum, for example, may be recorded photographically by filtering out the other wavelengths. Through the use of special infrared films, electromagnetic radiation reflected at wavelengths longer than those discernible by the eye can also be recorded photographically.

2. Multiband Cameras. These cameras permit the taking of more than one photograph simultaneously, each with a different combination of lens and filter. This allows simultaneous exposures of exactly the same area, with each exposure representing the energy reflected in various portions of the visible- and near-infrared segment of the electromagnetic spectrum.

3. Optical Mechanical Scanner. Scanners collect and electronically record energy reflected and radiated at wavelengths that fall within the range of 0.4 to 20.0 $\mu$m. Since only that portion from 0.4 to 0.7 $\mu$m is in the visible spectrum, information can be obtained by scanners that is not discernible by the human eye. An example is the determination of water temperature differences near discharges from nuclear power plants, a task which can be done very accurately using optical mechanical scanners.

4. Radar. Radar systems are active devices; that is, they transmit their own energy and collect the portion of this energy that is reflected from the illuminated terrain. This is in contrast to the other remote sensing devices that do not supply their own energy source, but measure only reflected or emitted energy and are called passive systems. Radar operates at longer wavelengths than any of the devices previously described and has an all-weather, day-and-night capability. Radar also has the ability to penetrate vegetation and to sense the terrain beneath.

Remote sensing is presently being performed by aircraft and by spacecraft, each having distinct advantages. Airplanes have the advantage of being able to perform specific sensing tasks over selected areas and to obtain greater resolution from aircraft altitudes. However, an airplane cannot match the overall synoptic coverage or the stable, vibration-free platform of a satellite. The initial cost of orbiting a satellite would be much higher than initiating an aircraft mission. However, if large surface areas are to be sensed or if repetitive coverage is required, the cost differentials are reduced and, in some instances, the satellite sensing may be the most economical.

## ERTS and Skylab

In 1972, NASA will launch the first Earth Resources Technology Satellite (ERTS) that will monitor the earth's resources on a global scale. The first launch, ERTS-A, will put a 1800-lb vehicle into a circular, near-polar orbit about 500 miles above the earth. The earth will be revolving beneath it, and by the time ERTS returns to the same spot on its next track, the earth will have revolved 1800 miles to the west. In 18 days it will have covered the world and begin making its second pass. This ability to monitor changes on the earth's surface that occur over time will be a valuable feature of satellite sensing.

ERTS will have a three-camera television system to provide imagery which can be converted to photos in three spectral bands — blue-green, red, and near-infrared. The camera operating in the blue-green portion of the spectrum will provide maximum penetration of water; the camera in the red portion will be useful for crop identification and delineation of soils; and the camera in the near-infrared portion will show maximum discrimination between land and water. Each of these photos will cover approximately 10 000 square miles.

ERTS-A and ERTS-B, which will be launched approximately 1 year after ERTS-A, also have multispectral scanners to measure energy radiated from the earth. ERTS-A will only be capable of measuring reflected energy, whereas ERTS-B will be able to measure both reflected and thermal energy.

Skylab will be another type of space platform for monitoring earth resources. This will differ from ERTS in that men will be placed into orbit and they will be collecting most of the data. Skylab or Earth Resources Experiment Package, as it is sometimes termed, will contain more sophisticated remote sensing devices than ERTS, resulting in a wider variety of remotely sensed data with better resolution. However, the amount of area covered by Skylab will be much less than that of ERTS.

## Organization and Management

In 1970, an interdisciplinary group was established at Pennsylvania State University with the capability of participating in projects involving the use of remotely sensed data of earth resources. This interdisciplinary group is called the Office for Remote Sensing of Earth Resources (Fig. 1) and is composed of personnel from the following disciplines agronomy, air pollution, civil engineering, climatology, economics, forestry, geology, geophysics, hydrology, meteorology, plant physiology, pattern recognition, regional planning, and soils. The Office for Remote Sensing of Earth Resources (ORSER) was formed as a division of, and with financial support from, the Space Science and Engineering Laboratory, which is a part of Pennsylvania State University's Intercollege Program (Fig. 1

The Space Science and Engineering Laboratory (SSEL) was established on September 1, 1965, by the act of the Board of Trustees of Pennsylvania State University. Administered by the Office of the Vice-President for Research for the university, it functions as a subunit of the Institute for Science and Engineering. A major purpose of the SSEL is to give focus to research and graduate study in the space sciences and space-related sciences and engineering, to provide support services of a technical and administrative nature to programs operated in existing departments, and to administer funds for the support of new programs developed within departments or on an interdepartmental basis. Major financial support for the laboratory has come from the NASA Office of University Affairs through the Sustaining University Program.

The reason ORSER was established by SSEL was to encourage interdisciplinary research activities involving remote sensing. To insure that this group functions in an interdisciplinary nature, a problems-oriented approach has been taken so that each problem or task is directly represented in the organizational structure. This will allow associates from various disciplines to work together toward a common goal rather than have each discipline devoted to a specific project.

The organization of ORSER is indicated in Figure 2. An associate professor of soils and an associate professor of electrical engineering serve as codirectors. Each task has a principal investigator or coinvestigators and they jointly make up the Coordinating Committee along with the codirectors. This Coordinating Committee oversees the research efforts of ORSER and encourages and coordinates future research endeavors. This committee will also meet frequently with the Advisory Committee for consultation, advice, and reports of progress. The Advisory Committee includes the deans of interested colleges or their appointed representatives. There is also direct communication between the Coordinating Committee and potential users of the research results. Examples of these potential users are:

1. Soil Conservation Service
2. Northeast Watershed Research Center
3. Susquehanna River Basin Commission
4. U. S. Forest Service
5. Ten Regional Clearinghouses in Pennsylvania
6. Pennsylvania State Planning Board
7. Pennsylvania Department of Environmental Resources
8. Pennsylvania Department of Transportation
9. Regional Planning Commissions
10. County Planning Commissions
11. Local Planning Commissions.

## Application and Interpretation

In applications of remote sensing techniques, consideration must be given to many factors, including amount, type, and quality of information to be collected, types of sensors available, and the type of platform (airplane or spacecraft) and its characteristics (altitude, speed, etc.). In the collection of remotely sensed data, various compromises must be made, and in many cases, airplanes and spacecraft may be used simultaneously to collect data.

Supporting information collected by other means is essential when evaluating and interpreting remotely sensed data. Such information is called "ground truth." Pennsylvania State University currently possesses a unique collection of ground-truth data for Pennsylvania. This will be an invaluable aid in establishing references and interpreting data obtained from spacecraft and other sources.

The primary objective of the interdisciplinary group at Penn State is to determine the usefulness of remote sensing techniques for the inventory of natural resources and land use, the determination of pollution sources and damages, and the analysis of geologic structure and terrain. The area selected for this study was a large river basin.

## The Susquehanna River Basin as an Area of Application

Since spacecraft remote sensing is most useful for coverage of large land areas. Pennsylvania State University has selected the Susquehanna River Basin for application of remotely sensed data from ERTS and Skylab. The reasons for choosing the basin include the facts that it (1) contains a wide variety of soils, vegetation, water bodies, and geological structures; (2) is located in geographical proximity to Penn State; (3) has considerable ground-truth data already available, including an excellent Susquehanna River Study of June 1970 by the Susquehanna River Basin Study Coordinating Committee; and (4) is of interest to various agencies of the Federal Government and to the States of Pennsylvania, New York, and Maryland.

The Susquehanna River Basin is the largest, undeveloped watershed in the Northeastern United States. The present population of the basin is 3.5 million and is expected to increase to 9 million in the next 50 years. The Susquehanna supplies 85 percent of the fresh water that flows into the Chesapeake Bay above the mouth of the Potomac River and, thus, the ecological balance in the bay could be seriously affected by upstream development on the Susquehanna.

In addition, the basin is located directly between the Chesapeake Bay and Lake Erie and, thus, forms a geographical tie between these two bodies which are both of great ecological interest today. It will be necessary to insure the proper utilization of the basin because we, as a nation, are committed to the restoration and maintenance of a healthy and viable natural environment. It will be the intent of ORSER to determine and demonstrate the role remote sensing might play in the regional resource management of the Susquehanna River Basin. This will hopefully involve direct participation by the Office for Remote Sensing of Earth Resources with the new Susquehanna River Basin Commission, recently established by the enactment of Public Law 91-575 (Susquehanna River Basin Compact).

Portions of the basin are undergoing extensive and rapid urbanization and in other areas, strip-mining operations are increasing. Powerplants, which have a dynamic influence on the ecology of the river basin, are present on the Susquehanna and more are proposed. The upper reaches of the Susquehanna are almost completely forested and should offer study areas for phenological phenomena, recreation, and forestry. Extensive snowfields also exist in these areas and they have considerable impact on the hydrology of the Susquehanna. These are considered examples of some of the areas where spacecraft data should be applicable.

## Interpretation of Spacecraft Data

A number of different tasks can be pursued because of the amount and variety of data to be collected by ERTS and Skylab, and because of the diversity of interests and backgrounds available in a university such as Penn State. The specific objectives of the work planned by ORSER in Pennsylvania and the Susquehanna River Basin are grouped into one of four areas of investigation as follows:

1. Inventory of Natural Resources and Land Use. The use of spacecraft data for purposes of inventory and survey of relatively large areas must be considered to have very great potential. The inventory of natural resources and land use offers great promise, not only to investigators in the various disciplines, but to planners and policymakers at all levels of the public sector. In the specific tasks listed below there is need for both detailed analysis by the individual investigators and for communication among investigators regarding their goals, analyses, and results. The specific tasks considered under this area of investigation are:

a. Identification and characterization of soil parameters

b. Location, inventory, and monitoring of strip-mining operations and pollution spoils

c. Survey and inventory of forest resources

d. Evaluation of potential recreation sites

e. Survey the initiation and progression of insect and plant disease epidemics

f. Collection and updating of data for multipurpose land use management

g. Development of natural resource inventory systems.

2. Geology and Hydrology. The geologically oriented tasks involve correlation and analysis of natural features associated with terrain analysis, as well as the effects of man-related ventures, such as mining operations and pollution spoils. Analysis of the orientation, distribution, shape, and type of the surface trace of geologic structures would follow the procedure of characterization, correlation to known geologic features, and application and utilization. From an inventory of known mineral and ground water deposits, their relationship to lineaments and fracture traces would be developed as a tool for area selection in mineral exploration and in ground water planning and utilization. Specific tasks for investigation are:

a. Characterization and analysis of geologic structures and terrain

b. Inventory of mineral resources and mines

c. Detection of ground water sources from drainage, lineaments, and fracture patterns

d. Determination of watershed runoff.

3. Pollution. The Susquehanna Basin is an area of contrasts with the upper reaches heavily forested and in an almost untouched condition, while the lower reaches are fairly well urbanized. This contrast in land use, along with extensive coal-mining operations, offers a unique area for pollution studies. It is the intent in this area of investigation to determine the role remote sensing might have in the detection of various types of pollutants, such as thermal pollution, acid mine drainage, and nutrient and chemical pollutants; the detection of the effects pollutants have on the environment; and the monitoring of pollutant types along with their environmental impacts. This area of investigation will involve the following tasks:

a. Monitoring the environmental effects of power generating plants

b. Detection of sources of acid mine drainage, monitoring seasonal discharges and determination of mixing patterns in other waters

c. Detection of air pollution damage

d. Definition and characterization of water quality problems in a large river.

4. Data Processing. The tasks in the area of data processing are of importance not only in their own right but also because of their usefulness to all other investigators. The tasks are primarily of an automatic or man-machine interactive nature, although visual photo-interpretive techniques are expected to be used extensively by many investigators. In addition to establishing format, specifications, programs, and procedures for all users of the automatic data processing facilities, pattern recognition techniques and programs are being developed and made available to all investigators. A joint university-industry task is planned in which a man-machine interactive system will be used for analysis of imagery.

## Conclusion

The general objectives of this interdisciplinary effort in remote sensing include the application of remote sensing methods to various specific tasks, the development of interpretation techniques, and the application of remote sensing in regional resource management. The approach to be taken is interdisciplinary in nature, with individual investigators not only concentrating on tasks for which they are specifically trained but also working closely with others having similar or related interests. Tasks within each area of investigation will certainly be coordinated with each other, and in many cases, with tasks in another area. Investigators of the task on the inventorying of strip-mining operations, for example, will be working closely with personnel involved in the detection of acid mine drainage and both of these tasks are related to the task of inventorying mineral resources and mines. The tasks, involving forestry inventory, plant diseases and insects, air pollution damage, and environmental effects of power generating plants, can be expected to involve much interchange of information. In most tasks, the data processing and pattern recognition applications are expected to be similar. When investigating a large river basin it is not feasible to cover all possible problems within each area and, therefore, selected objectives or tasks, for which ORSER has a specific talent and capability, have been chosen. It is felt that these selected tasks do, however, represent major problems in the Susquehanna River Basin and can serve as the basis for a major unified interdisciplinary attack on problems using remotely sensed data.

The anticipated results, in general, will be important for making resource management and land-use policy decisions with the basin. In addition, certain results offer quick return possibilities, such as evaluation of structural lineaments for use as a tool in interpreting geological structures, inventorying of strip-mining and land use changes, and detection and monitoring of pollutants. University training in remote sensing at both the undergraduate and graduate level will be performed. The effectiveness of not only interdisciplinary but joint university-industry research will be evaluated.

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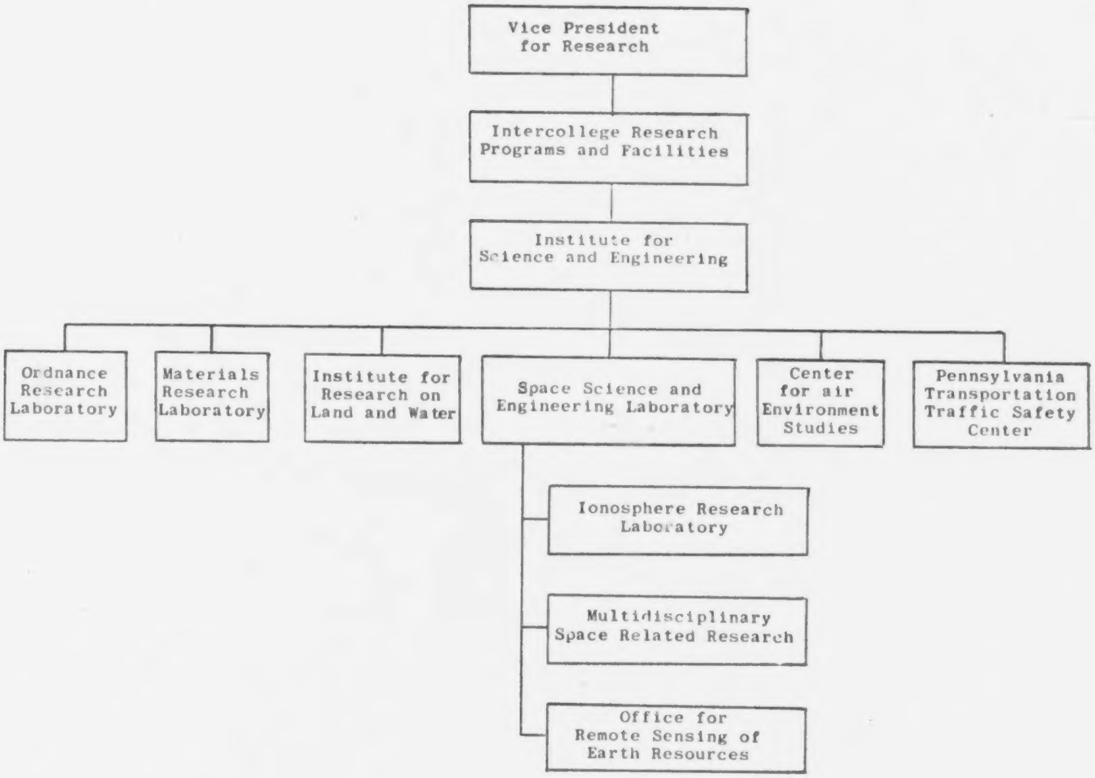
Vice President for Research
Intercollege Research Programs and Facilities
Institute for Science and Engineering
Ordnance Research Laboratory
Materials Research Laboratory
Institute for Research on Land and Water
Space Science and Engineering Laboratory
Center for air Environment Studies
Pennsylvania Transportation Traffic Safety Center
Ionosphere Research Laboratory
Multidisciplinary Space Related Research
Office for Remote Sensing of Earth Resources

Figure 1. Organizational chart of Pennsylvania State University's Intercollege Program.

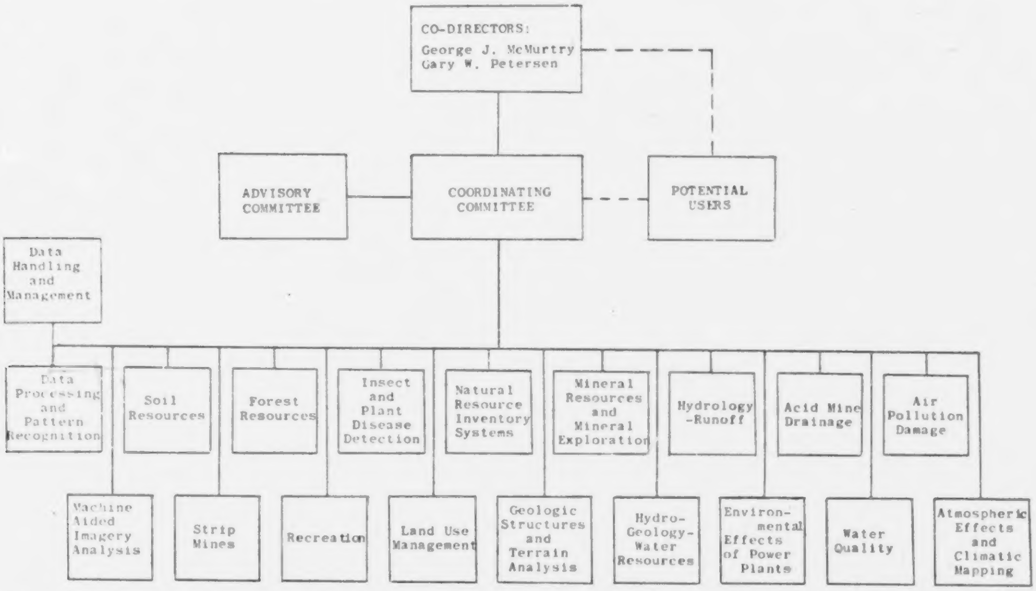
CO-DIRECTORS:
George J. McMurtry
Gary W. Petersen
ADVISORY COMMITTEE
COORDINATING COMMITTEE
POTENTIAL USERS
Data Handling and Management
Data Processing and Pattern Recognition
Soil Resources
Forest Resources
Insect and Plant Disease Detection
Natural Resource Inventory Systems
Mineral Resources and Mineral Exploration
Hydrology -Runoff
Acid Mine Drainage
Air Pollution Damage
Machine Aided Imagery Analysis
Strip Mines
Recreation
Land Use Management
Geologic Structures and Terrain Analysis
Hydro-Geology-Water Resources
Environmental Effects of Power Plants
Water Quality
Atmospheric Effects and Climatic Mapping

Figure 2. Organizational chart of the Office for Remote Sensing of Earth Resources (ORSER).

# ORBITAL SURVEYS AND STATE RESOURCE MANAGEMENT

By George Wukelic
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Aerospace Mechanics Division
Battelle Columbus Laboratories
Columbus, Ohio

and

T. L. Wells and B. R. Brace
State of Ohio
Department of Development

## Abstract

The citizens of the individual states should benefit substantially, both immediately and in the future, from the results of earth surveys from manned and automated spacecraft. This paper describes how a state, such as Ohio, with highly diversified industry, agriculture, and geography, proposes to use orbital survey data and related space capabilities to manage its resources, attack increasing environmental problems, and plan future developments. Certain and anticipated short- and long-range benefits are described. The State Government of Ohio foresees opportunities, challenges, and potential benefits in orbital surveys not only for government management responsibility but also for its constituency by providing alternative approaches to resource and environmental problems heretofore unavailable.

## Introduction

The purpose of the forum is to acquaint you, the nonaerospace public, with the benefits expected to result from satellite earth-resource surveys. This discussion will be limited to the resource-management implications of such surveys, and more restrictedly, as they are currently viewed in the State of Ohio. Actually, the opportunities, challenges, and potential benefits inherent in using automated and manned spacecraft for resource-management activities can be looked at in several ways, depending on one's point of view. That is, whether you are a space scientist (like myself), a state planner (like my coauthors), or an interested citizen (like yourself).

The space scientist's view of resource management using orbital surveys is, of course, one of utmost enthusiasm (Fig. 1). He sees the tremendous opportunity to expand data acquisition, the challenge orbital surveys provide to data management and analysis specialists, and their potential for revolutionizing resource-management decisionmaking practices.

State government personnel, represented in our discussion by the state planner, are faced with a mountain of increasing resource and environmental issues, problems, and needs (Fig. 2). He sometimes views the same data collection opportunity negatively in that he fears further saturation of his already largely unused and often misused data base. His challenge is to accurately assess the user potential inherent in satellite earth surveys in order to insure that their ultimate potential for supporting a practical, resource/environmental-management system can be achieved.

You, the taxpaying public (Fig. 3), on the other hand, most likely view this new cry of "satellite surveys for citizens" as another NASA propaganda campaign to turn around declining space budgets and, thus, as an opportunity to increase rather than stabilize the existing tax burden. Your challenge is one of trying to understand how anything as complex as multispectral photography, infrared spectrometry, and microwave radiometry can possibly relate to your life style. Reminiscent of several past experiences, you tend to view the potential here as another example of more big-space "talk" but little new down-to-earth benefits. I hope to alter this view somewhat.

Although viewpoints differ, the objectives, design features, data collection, and relay capabilities of both the automated Earth Resources Technology Satellite (ERTS) and manned Skylab[1] spacecraft systems were presented in previous sessions of this Congress and will not be repeated here. As I said earlier, I plan to limit my discussion to orbital survey data utilization and, more specifically, to how we hope to use this emerging space capability for resource-management interests in Ohio. Accordingly, most of this discussion is not what we have done, but rather what we plan to do and what practical benefits we anticipate.

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[1] Skylab when referred to in this paper is always in connection with the Earth Resources Experiment Package (EREP).

## Resource-Management Problems and Plans in Ohio

Ohio is one of the most heavily populated states in the nation, has a highly diversified industry and agriculture, and possesses a variety of geographic features. Also, Ohio, like all progressive and developing states, has a serious resource and environmental management problem which grows more serious daily.

Following the national trend, Ohioans are becoming more concerned about reckless environment and natural resource habits and are placing more pressure on state government officials and legislators to change this policy. Accordingly, new tools such as automated and manned spacecraft with their sophisticated imagery and relay capabilities must be incorporated, as appropriate, into resource and environment management problem solving.

## Ohio ERTS and Skylab Plans

In response to the most timely NASA/ERTS and Skylab opportunities, the State of Ohio, in concert with the Battelle Columbus Laboratories (BCL), proposes to undertake a comprehensive, multidisciplinary assessment of the state-level utility of these experimental orbital survey programs. The joint program is somewhat unique in that it enlists the expertise of an unusual but necessary combination of technical, economic, and state-planning and program management specialists. The objectives of the proposed program range from one of establishing an experimental Ohio ERTS/Skylab data utilization facility to the developing of a methodology for evaluating the impact of these satellites on resource-management goals in Ohio. The broad interface that exists among the various units of Ohio State Government, ERTS and Skylab data, and potential application/user areas has been determined (Fig. 4). The specifics of this figure are not important here. It is included only to illustrate the extensive utilization potential for satellite surveys at the state level.

Although the initial plan is to investigate user-oriented applications in all the disciplines involved in orbital surveys, the main thrust of the Ohio ERTS/Skylab program is focused on ascertaining the relevance of these space programs to problems, issues and needs in the more critical Ohio resource and environmental-management areas of:

1. Environmental quality,

2. Land use, and

3. Agriculture and forestry.

Secondary interests relate to the geological, hydrological, and meteorological utility of orbital surveys primarily as they impact on broader interdisciplinary interests involving Ohio's Lake Erie and Appalachia development responsibilities.

A map of the geographical areas selected as initial Ohio study sites and areas of interest for ERTS and Skylab data is shown in Figure 5. Collectively, these represent agricultural, forestry, recreational, wetland, wildlife, urban, glaciated, nonglaciated, topographically rugged, topographically flat, river basin, lake, and transportation features. It is also planned to collect correlative surface-truth data (aircraft and ground) for the five principal study sites, as required to meet discipline analysis objectives involving primarily photogrammetric comparisons of multispectral photographs. The relation of the proposed study sites to discipline/user interests is shown in Figure 6.

In order to test the state value of satellite relay capabilities, a data collection platform is to be installed in the Columbus vicinity. This platform will be mobile and will be designed to collect a multidisciplinary set of data. This effort will be in addition to the ongoing Environmental Protection Agency's water-quality monitoring program in southern Ohio and the 20-station platform relay network planned for Lake Erie studies by the NASA facility in Cleveland.

## Anticipated Benefits

Technical Benefits. From this broad multidisciplinary involvement in NASA/ERTS and Skylab programs, we hope to identify specific satellite data and data relay functions that can be incorporated into Ohio resource-management activities. Specifically, the extent that decisionmaking and policy implementation within the various units of state government are unaffected, disoriented, or enhanced by these initial orbital survey experiments will be determined. Currently we are optimistic and are anticipating explicit benefits to occur in each of the principal discipline areas of interest. In agriculture (Fig. 7), for example, we hope initially to capitalize on the capability of satellite surveys to provide repetitive gross crop inventories and eventually to attempt crop stress and disease monitoring studies. Expensive soil moisture survey requirements existing may be fulfilled in part by satellite relay techniques, too. Utilization of orbital surveys for gross inventory and disease and pollution assessment functions of Ohio's timber resources (Fig. 8) also appears possible. Forest fire damage assessment is considered a good state-level applications candidate, but routine use for forest fire detection will have to await operational satellite development.

Our hopes for land-use applicability of orbital survey data are among the highest (Fig. 9). They range from plans to update the state's land-use survey of 1960 (which is seen in the background; completed in 1967) using ERTS and Skylab data to support experimental preparation of base maps, topographic maps, photomosaics, and other special-purpose maps for demographic, urban development, and transportation interests.

Another major and currently critical benefit category that we hope to exploit initially is that of environmental quality. We have explicit plans to test satellite imagery and data relay techniques considered applicable to air quality controls, which are to be implemented in Ohio in the next few years (Fig. 10). The use of the imagery data, and more important, satellite remote relay opportunities in water quality management are even more enthusiastically being considered (Fig. 11), as are plans for applying orbital survey capabilities to controversial strip-mining reclamation efforts in Ohio (Fig. 12).

The anticipated use of orbital surveys for Ohio's geological, hydrological, and oceanographic interests (Lake Erie being considered Ohio's ocean) is of less certainty (Fig. 13). Flood-plain management and Lake Erie shore-erosion research are certainly areas wherein we hope to apply satellite-acquired data. Orbital data on cloud, snow, ice, and fog conditions in Ohio (Fig. 14) are to be studied primarily as they relate to other discipline interests.

Other Benefits. In addition to the technical (discipline-oriented) benefit possibilities of ERTS and Skylab, we anticipate several byproduct benefits to other aspects of state government which indirectly affect resource-management activities in Ohio. These can be grouped according to the expected time frame of occurrence (Fig. 15). Short-term benefits, for example, are those associated with experimental orbital surveys; whereas long-term benefits are more characteristic of down-the-road, operational possibilities.

We foresee that some immediate benefits will occur simply by our active participation in the orbital survey programs. In terms of information, for example, the need to obtain correlative aircraft- and ground-truth data will automatically expand the state's resources and environmental data base regardless of the value of the orbital survey data. Also, data-handling experiences will be of immediate interest to a plan currently under consideration to establish a new budgeting and planning unit in the office of the governor. Another immediate benefit of major state interest relates to expanded interagency communications. The ERTS and Skylab programs, as planned, require extensive interagency coordination and dialogue which will provide reciprocal insights into other agencies' activities, problems, priorities, and products. This could help fight bureaucracy from within and force agencies to function more effectively to survive. Also, today's students desire more relevant subjects. Remote sensing; resource and environmental management; and space technology, as applied to people-oriented needs (such as orbital surveys); represent new and relevant educational opportunities. In this connection, Ohio State University recently announced plans to introduce new courses on the application of remote sensing technology, which will interface nicely with the planned Ohio ERTS and Skylab involvements.

Most significant short-term benefits are considered possible in the categories of legislation and state government reorganization. The Ohio Legislature is considering numerous natural resources and environment bills, the development, implementation, and enforcement of which could be heavily influenced by automated and manned satellite capabilities. The distribution of appropriate satellite-acquired photographs, for example, could provide broader perspective on environmental issues requiring legislation. Likewise, Ohio's ERTS and Skylab experiences and findings should prove valuable to studies in progress concerned with state reorganizational possibilities. This will be especially so for considerations regarding how the state should be reorganized to be most responsive to increasing resource and environmental issues, the delivery of state services, and associated Federal controls and funding opportunities.

On a longer-term basis, we anticipate benefits to accrue from operational orbital surveys which will impact on all Ohio resource- and environment-related problem areas. However, most important are those potential benefits anticipated in the budget, development, and employment categories. Certainly, even if only partially successful, anticipated cost savings inherent in operational orbital surveys will make many new and necessary resource and environmental programs possible. A large percentage of these are currently being rejected solely on economic grounds.

Air and water quality regulations and natural gas shortages pose serious national, industrial, and community development problems. Repetitive orbital survey data could be quite useful in the long-term planning of the types and locations of new industries and new towns in Ohio. A technically sound and positive attitude toward planned industrial expansion is essential to maintaining a healthy economy in Ohio, as well as to improving the unemployment situation, both of which will worsen if unreasonable environmental restrictions are imposed.

## Conclusion

I have tried to present a brief overview of plans and hopes for utilizing orbital surveys for resource and environment management interests in Ohio. To achieve many of the anticipated benefits requires th the long-range goal of establishing a comprehensive state resource-management system, supported by new technology, including an operational network(s) of automated and manned satellites, be accomplishe Technical know-how and user interests are believed adequate to fulfill this goal. However, effective and honest resource and environmental management in any state will always be people dependent — therein lies the social responsibility that constitutes a challenge to us all.

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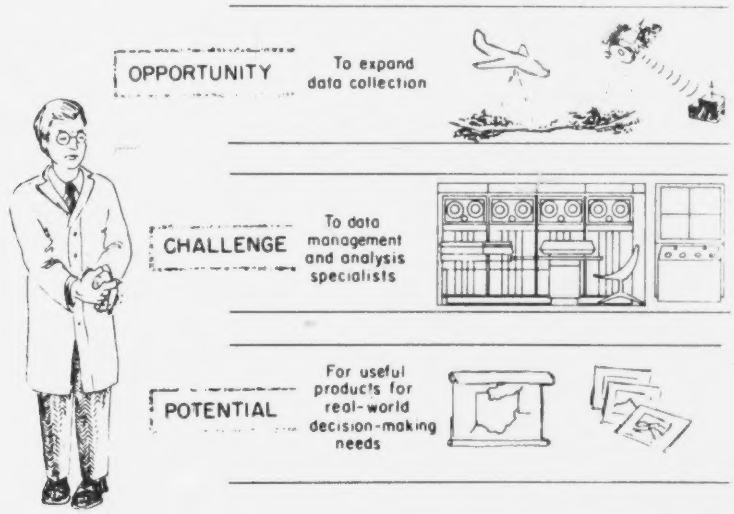

OPPORTUNITY
To expand data collection
CHALLENGE
To data management and analysis specialists
POTENTIAL
For useful products for real-world decision-making needs

Figure 1. Space scientist's view of resource management via orbital surveys.

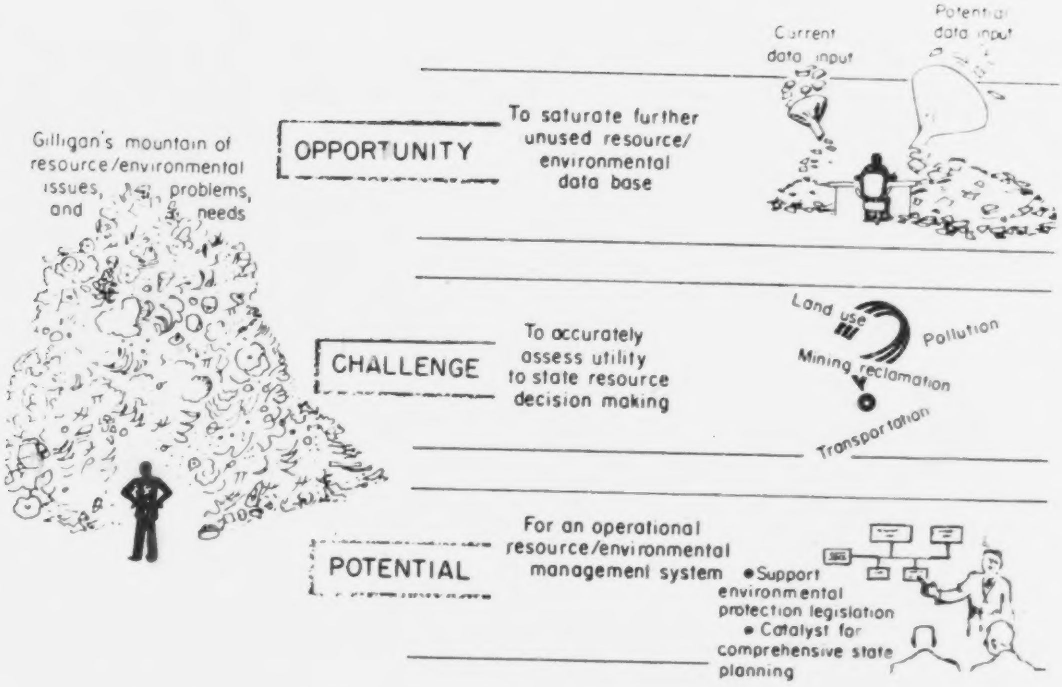

Gilligan's mountain of resource/environmental issues, problems, and needs
OPPORTUNITY
To saturate further unused resource/environmental data base
Current data input
Potential data input
CHALLENGE
To accurately assess utility to state resource decision making
Land use
Pollution
Mining reclamation
Transportation
POTENTIAL
For an operational resource/environmental management system
• Support environmental protection legislation
• Catalyst for comprehensive state planning

Figure 2. State planner's view of resource management via orbital surveys.

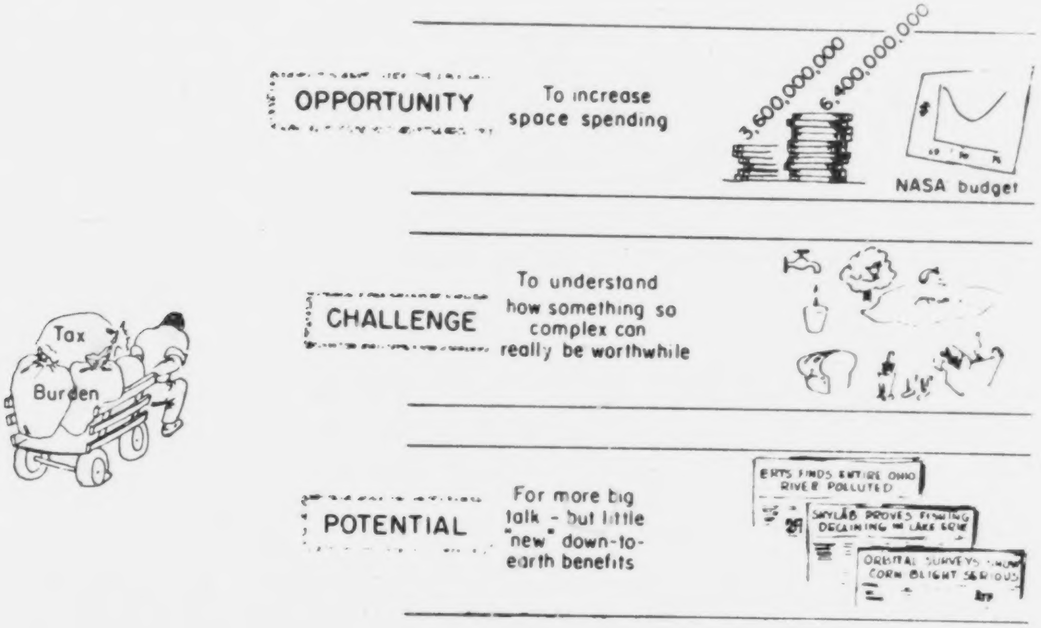
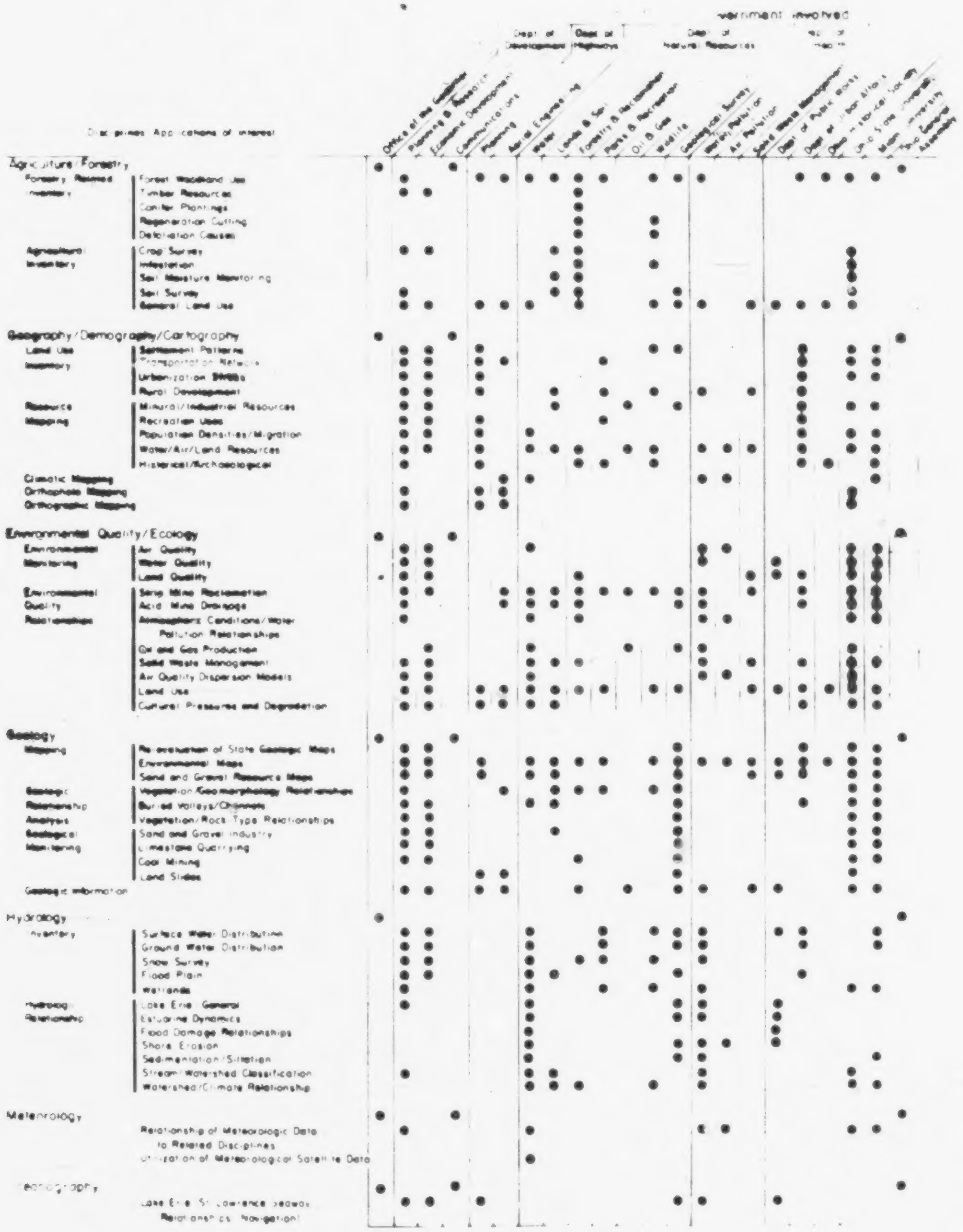

Tax
Burden
OPPORTUNITY
To increase space spending
3,600,000,000
6,400,000,000
$
NASA budget
CHALLENGE
To understand how something so complex can really be worthwhile
POTENTIAL
For more big talk - but little "new" down-to-earth benefits
ERTS FINDS ENTIRE OHIO RIVER POLLUTED
SKYLAB PROVES FISHING DECLINING IN LAKE ERIE
ORBITAL SURVEYS SHOW CORN BLIGHT SERIOUS

Figure 3. Public's view of resource management via orbital surveys.



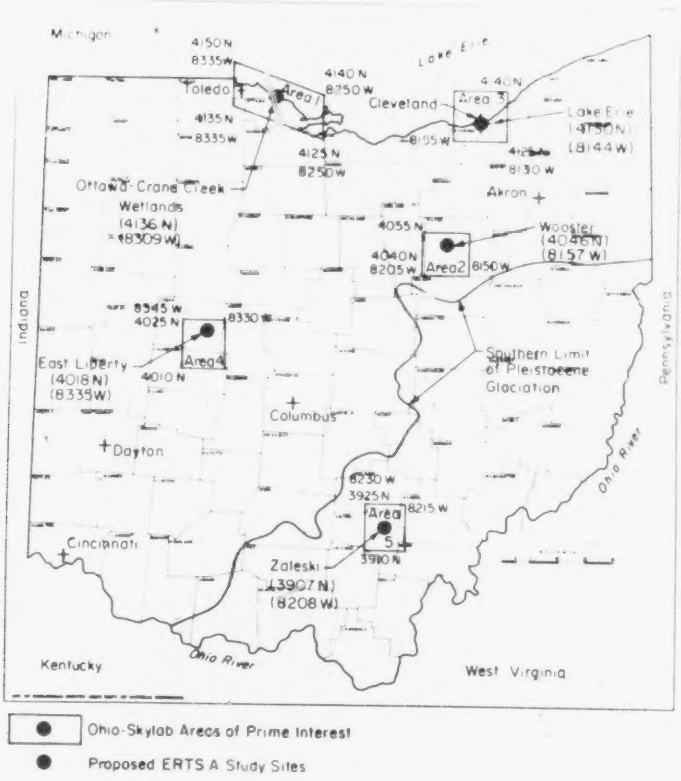

Michigan
Lake Erie
4150 N
8335 W
Toledo
Area 1
4140 N
8250 W
Cleveland
Area 3
4140 N
Lake Erie
(4150 N)
(8144 W)
4135 N
8335 W
8155 W
4125 N
8250 W
4125 N
8130 W
Ottawa-Crane Creek
Wetlands
(4136 N)
(8309 W)
Akron
4055 N
Wooster
(4046 N)
(8157 W)
4040 N
8205 W
Area 2
8150 W
Indiana
8345 W
4025 N
8330 W
Area 4
East Liberty
(4018 N)
(8335 W)
4010 N
Southern Limit
of Pleistocene
Glaciation
Pennsylvania
Columbus
Dayton
Ohio River
8230 W
3925 N
Area 5
8215 W
Cincinnati
3910 N
Zaleski
(3907 N)
(8208 W)
Kentucky
Ohio River
West Virginia
Ohio-Skylab Areas of Prime Interest
Proposed ERTS A Study Sites

Figure 5. Location of Ohio areas of interest and study sites for ERTS/Skylab.

| | Discipline | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Agriculture | Cartography | Demography | Ecology | Environmental Quality | Forestry | Geography | Geology | Hydrology | Meteorology | Oceanography |
| Study Sites | | | | | | | | | | | |
| Lake Erie | | | | | + | | | | + | | + |
| Ohio Transportation Center | | + | | | | | + | | | | |
| Ottawa-Crane Creek Wetlands | | | | + | + | | | + | + | | |
| Wooster Agricultural Center | + | | | | | | | | | | |
| Zaleski State Forest | | | | | | + | | | | | |
| Locales of Opportunity | | | | | | | | | | | |
| Adams County | | | | | | | | + | | | |
| Alum Creek Reservoir | | | | | | | + | | + | | |
| Cleveland | | | + | | + | | + | | | | |
| Columbus | | + | + | | | | + | | | | |
| Coshocton County | | | | | | | | + | | | |
| Glaciated Region | + | | | | | | | + | | | |
| Lucasville | | | | | | | | + | + | | |
| Nonglaciated Region | | | | | | + | | + | + | | |
| S.E. Ohio | | | | | | | | + | | | |
| McConnelsville | | | | | + | | | | | | |
| State of Ohio (as a whole) | | + | | | | | | | | + | + |

Figure 6. Relationship of study sites and disciplinary interests.

GROSS INVENTOR
-- AGRICU

Figure 7. Orbital survey — agriculture.

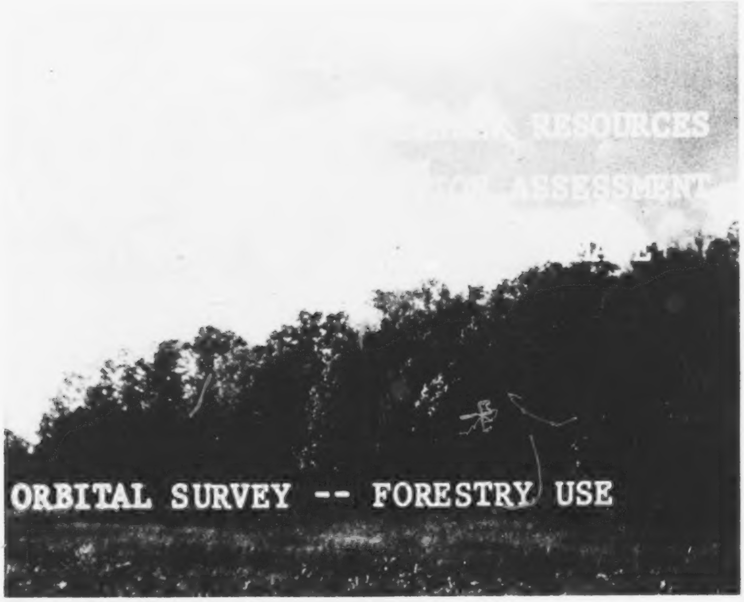

RESOURCES
ASSESSMENT
ORBITAL SURVEY -- FORESTRY USE

Figure 8. Orbital survey — forestry use.

LAND USE - 1960
STATE OF OHIO

Figure 9. Orbital survey — land use.

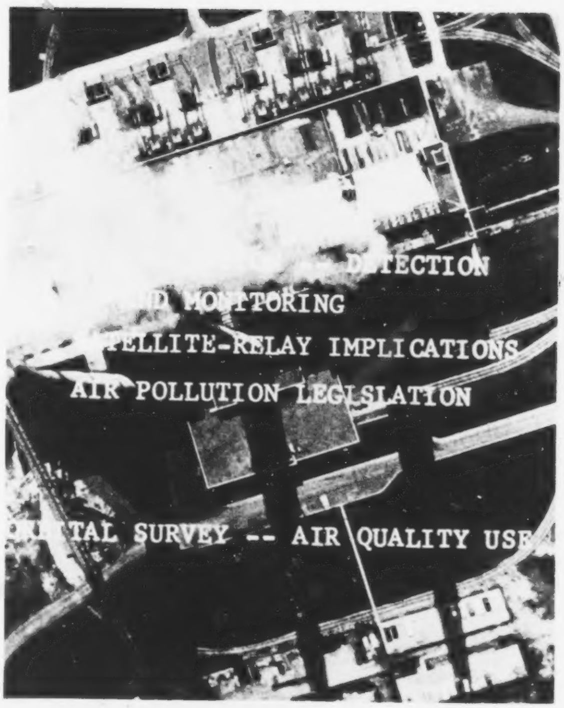

DETECTION
D MONITORING
TELLITE-RELAY IMPLICATIONS
AIR POLLUTION LEGISLATION
TAL SURVEY -- AIR QUALITY USE

Figure 10. Orbital survey — air quality use.

EMENT
LICATIONS
STREAM MONITOR CONTROL CENTER
Ohio Department Of Natural Resources
SLATION
SURVEY -- WATER QUALITY USE

Figure 11. Orbital survey — water quality use.

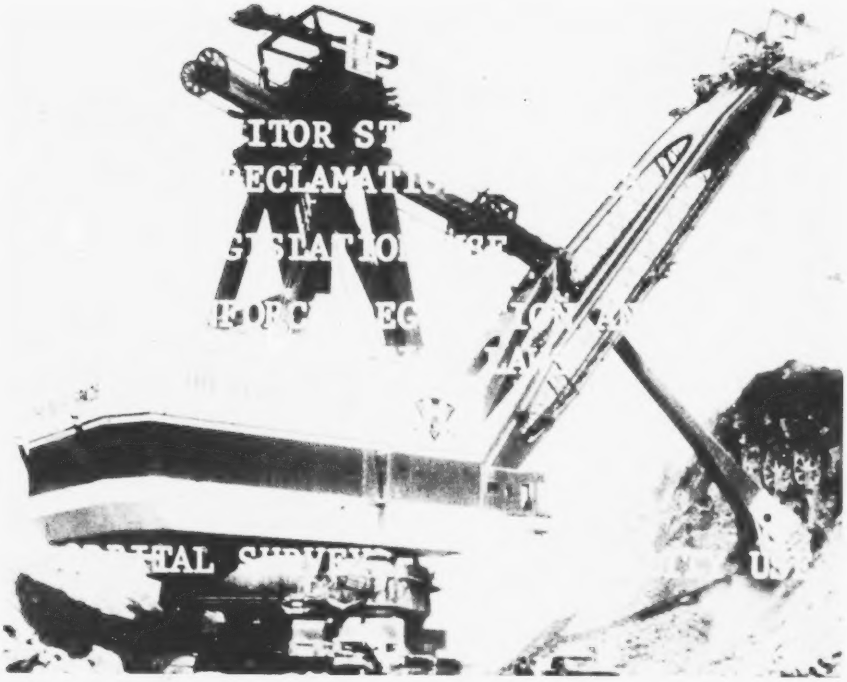

ITOR ST
RECLAMATIO
GISLATION USE
ORBITAL SURVEY
US

Figure 12. Orbital survey — land quality use.

LAND USE
NEAR-SHORE SEDIMENTARY STUDIES
LAND USE IMPLICATIONS
GEOLO

Figure 13. Geology/hydrology/oceanography (orbital data).

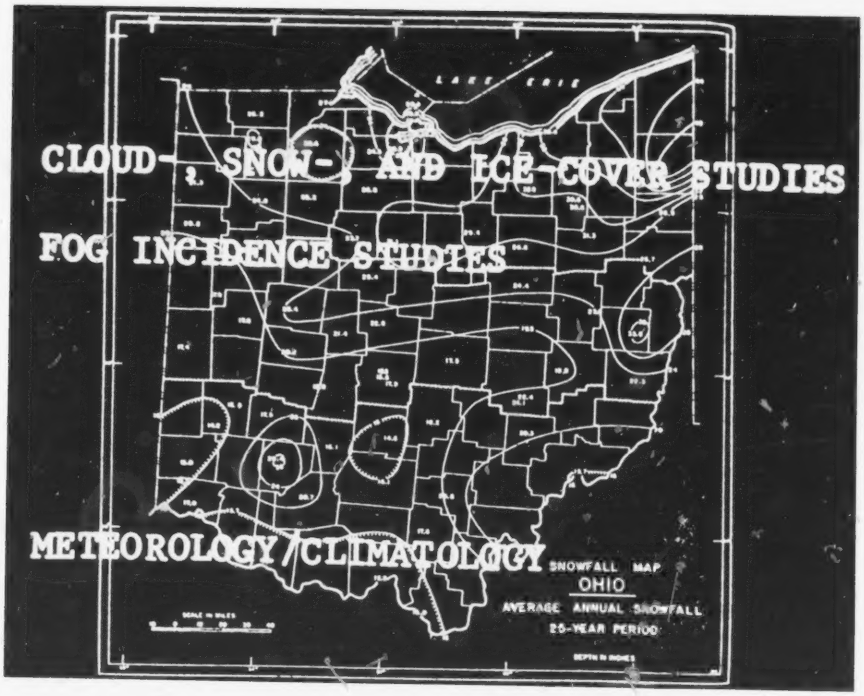

CLOUD-, SNOW-, AND ICE-COVER STUDIES
FOG INCIDENCE STUDIES
METEOROLOGY/CLIMATOLOGY
LAKE ERIE
SNOWFALL MAP
OHIO
AVERAGE ANNUAL SNOWFALL
25-YEAR PERIOD
DEPTH IN INCHES
SCALE IN MILES

Figure 14. Meteorology/climatology (orbital survey).

| | Experimental Orbital Surveys | | Operational Orbital Surveys |
|---|---|---|---|
| | Short-Term Benefits | | Long-Term Benefits |
| Problem Elements | Assured | Possible | Possible |
| Budget | | + | + |
| Information | + | | + |
| Legislation | | + | + |
| Communications | + | | + |
| Employment | | | + |
| Industry and Community Development | | + | + |
| Organization | + | + | + |
| Education | + | | + |

Figure 15. Anticipated orbital survey benefits to resource-management-related problems in Ohio.

# RIVERBED FORMATION

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## Abstract

The general fluvial processes that work to form a riverbed and produce the characteristic pattern of either meandering, braided, or straight are reviewed. A method for quantification of river pattern and correlation, with the basic hydraulic characteristics of discharge and slope, is presented. Additional characteristics of a river system may be deduced from high-quality photography and imagery obtained from either aircraft or space platforms.

## Introduction

Since the establishment of Colorado State University as the land-grant college for the State of Colorado in 1870, one of the main emphases of both basic and applied research has been in the broad subject category of water use. Consequently, subjects concerning rivers and river behavior have been of prime concern, particularly as they relate to river control, navigation, pollution, and water resource management. In connection with these endeavors, engineering staff members of Colorado State University have long maintained a considerable amount of direct working relationships with Federal and State agencies, and private corporations both here in the U.S. and abroad.

In more recent years, an obvious need has emerged for studying a particular river problem from a broader systems approach. The amount of sediment being carried in a river at a particular location, proposed for a water supply intake for a major city, for example, may be the combined result of a heavy rainfall on some new timbering operation hundreds of miles upstream. River behavior is a complex reaction often resulting from a variety of manmade and/or natural inputs.

As a result of the need for a broader overview of a river, certain remote sensing procedures have been utilized by engineers at Colorade State University during the past 10 years in order to provide supplemental information about larger and larger parts of a given river system. An aircraft platform, with altitude limitations of about 30 000 ft above the mean sea level, has provided good overviews of many important characteristics of rivers. Three basic sensors have been used: a Wild RC-8 precision mapping camera (with a variety of film-filter combinations), a multiband camera and regular aerial cameras with selected film-filter combinations, and thermal infrared line scanners. Rivers located in the Rocky Mountain areas of Colorado, Wyoming, and Montana, to the mighty muddy Mississippi in the lower Gulf region, have been investigated.

During the course of these investigations a great deal of experience has been gained as to what characteristics of a river system can be evaluated using certain sensors from an aircraft. Now with observations from an orbital platform a practical reality, one will finally be able to obtain the vital, additional dimensions of synoptic, sequential overviews of total river systems. An extension of our understanding of the use and analysis of remote sensor output from an aircraft platform can now be immediately applicable to orbital survey data. This paper will discuss certain characteristics of river systems that are amenable to determination from orbital altitudes.

## Scope

A riverbed is the result of a long-term process of transport and deposition of sediments by the flowing water. The total riverbed is often characterized by an impermeable or semipermeable boundary filled with layers of cobbles, gravel, sand, silt, clay, and organic material. The live stream may only occupy a small portion of the total width of the riverbed. The overbank area or flood plain is often covered with dense growths of vegetation and may extend for considerable distances on either side of the main river.

The river and total flood plain, as a unit, is the target of interest. Viewed in this total context using a variety of sensors, one can extract valuable information as to the geologic development of the riverbed, determine the present fluvial processes at work, and make certain predictions as to what the river behavior will be in the near future.

The pattern (planimetric shape) of the flowing stream may be generally classified as either meandering, braided, or straight (Fig. 1). Streams have a natural tendency to meander, but many streams have a braided pattern, and a very few have straight patterns. Each of these patterns indicate a particular set of circumstances regarding the flowing water and the riverbed conditions. The main subject emphasis of this paper, and something that is particularly feasible from orbital altitudes, is: (1) the general identification of stream pattern, and (2) the use of certain pattern characteristics from meandering streams for both river-flow and river-slope predictions.

These predictions (estimates) of flow and slope are tremendously important for water resource planning purposes. A comparison of relative water yields from adjacent basins, for example, should be immediately apparent to a trained interpreter from a cursory observation of either the corresponding photograph or imagery. Recent work at Colorado State University for determining the correlation between meander river pattern characteristics and river flow and slope has been accomplished [1]. Results of these studies clearly indicate the potential of satellite observations for this purpose.

A considerable amount of additional qualitative information about the river-system environment may be obtained from satellite observations. Examples of each of these characteristics will also be illustrated in the following text.

## General Discussion of River Patterns: Braided, Meandering, or Straight

River channel patterns have been generally classified into three categories as braided, meandering, and straight [2]. These categories are neither all encompassing nor mutually exclusive; the stream pattern may change from one type to another over relatively short stretches or may consist of combinations [3]. However, river-channel patterns can be divided into two broader main categories: (1) single channel, and (2) multiple channel. Single-channel pattern can be either meandering, straight, or braided. The multiple channel does not necessarily imply braided, and can be branching channels formed in the process of alluvial fan building.

Meanders have also been classified as regular or irregular, single or compound, acute or flat, and sine, parabolic, circular, or sine-generated curves [4].

Straight channels over any sizable distance are a rarity, although steep channels in fairly uniform bed material may develop broad, shallow cross sections and can maintain relatively straight alignment for considerable distances [4].

Braided Pattern. The braided stream pattern has been attributed to steep slopes and/or high bedload concentration [5]. Although a steep stream may tend to develop a braided pattern, the general direction of the channel as a whole tends to be relatively straight. The channel is generally quite wide, relative to the depth, and ordinarily has a fairly flat bottom. Braiding generally occurs in channels carrying sand or coarser material as bedload.

Braided streams have a very characteristic pattern on an aerial photograph. Color infrared photography can enhance the intricate pattern and detail and often help identify the age of the particular braided channel; that is, to discriminate between vegetated and nonvegetated islands, and also to render the location of channel remnants.

The engineering significance of braided channels and the associated design problems to be considered for bridge construction, for example, are very important. Considerable bedload is in motion, and streambed and bank scour can be easily induced.

The reasoning for straight sections of braided channels was discussed by Chitale [4]. He noted that: (1) the continuity of the transverse bed profile was broken by numerous islands and/or submerged bars and (2) the range of bed material sizes was greater than in straight channels with no braiding.

These two factors tended to disrupt the homogeneity of the flow and dampen the tendency for transverse velocity components. Curvilinear flow, such as found in a meandering channel, was inhibited and therefore alignment was relatively straight except for the possible effect of channel boundaries.

For shallow streams of uniform depth and flowing with banks full, Brice [6] found that the growth of bars and/or islands in the channel not only divided the flow into braids but also reduced the water width to a value less than the bank-full width.

For a given discharge and bed material size, Brice found that braided sections of a river had steeper channel slopes and greater effective widths than meandering sections of the same river [6]. He cautioned, however, that no general statement about relation of valley slope to channel pattern can be made unless the other significant variables are specified, that is to say, bank erodibility, bed material, and discharge.

Large braided rivers, observed by Leopold and Maddock were to be characterized by wide channels, rapid shifting of bed material, and continuous shifting of the river course [7]. Reaches within a single-channel river having steeper slopes tended to be braided. The close relationship between meandering and braided patterns could be recognized in a braided stream; the individual branches of a braided stream definitely meandered. In plan view, however, the overall channel course of a braided stream was less sinuous than a meandering course with similar discharge. Sediment transport and deposition were found to be the essential ingredients for braiding [8].

The author has observed, on the North and South Platte Rivers of western Nebraska, relatively clear water with high rates of bedload movement in braided patterns. A braided pattern does not necessarily imply that a channel is overloaded, since "poised" or "degrading" channels have been recognized as braided [6, 8].

Rivers have been found to tend to braid where: (1) bank caving is active, (2) the slope is steep and sediments are easily erodible, or (3) the slope is excessively low and the total sediment load is great [9].

Fahnestock observed that glacial streams changed in pattern from meandering to braided with high summer discharges and returned to meandering with the advent of lower late-summer discharges. He found that both braided and meandering sections can occur where the stream is aggrading, poised, or degrading. The pattern does not conclusively define river regime. Fahnestock emphasized that the braided pattern cannot develop without bedload. He considered, in his investigation of the White River, the braided pattern to be caused by basically the following conditions: (1) erodible banks, (2) rapid and large variation in discharge, (3) steep slope or excessively low slope, (4) abundant load, and (5) local incompetence for sediment transport [10].

Meander Pattern. Meandering channels are a most common pattern found in a variety of situations from steep mountain slopes providing an alluvial cone to the deltaic environment. Meandering rivers can have bed material ranging from large cobbles to fine-grained silt. A gradual reduction of tortuosity ratio was found with an increase in slope [5]. Dominant discharge, which controls meander wavelengths, is a range of flows (possibly falling stage flows) somewhere between mean discharge for the month of maximum discharge to the annual mean discharge. There was some evidence of the effect of valley slope on meander wavelength. In cases of bank-full and overbank floods, the main current of the river takes on a valley-axial direction of flow, and during very large floods the flood plain acts as a river channel [11].

Wide, shallow channels are generally associated with lesser tortuosity. Also, since valley slope provides the force which tends to straighten the channel alignment, the higher the mean velocity the flatter the curvature required [4].

The values of tortuosity ratio (ratio of thalweg length to valley length) greater than 5.5 are rarely found in the field. This was the limiting value for idealized circular meanders. The reasoning for rivers ordinarily developing meanders in narrow, deep sections, but not in wide and shallow ones are listed:

1. Narrow, deep channels with low velocities allow easy adjustment of channel section conducive to flow concentrations at one bank or another and create conditions favorable to meandering. Wide, shallow channels with high flow velocities limit any nonuniformity of flow to a local effect, which dissipates in a short length without affecting the channel as a whole.

2. For very tortuous channels, the centerlines of the bends become close to each other, and consequently, the width of the channel must be small, or, alternately, the meander shape dictates that width of channel increase with decrease in tortuosity.

3. Flow curvature creates superelevation and transverse velocity components. In wide, shallow channels the relative height of roughness elements

to flow depth is greater than in deep channels. Consequently, such transverse components are minimized because of friction on the boundary [4].

Most meandering rivers have a ratio of radius of curvature to channel width in the range of 2 to 3. Size of bends appear to be proportional to the size of the river; the repeating distance between bends, width of the channel, and the radius of curvature are the basic dimensions [2].

Discharge was the most important single factor affecting the geometry of a meandering channel. The width of meandering channels is greater than straight channels having no well-developed shoal pattern; and that high sediment loads required steeper slopes and wider channels [12].

Schumm concluded, as did Leopold and Wolman, that meandering is a principal means of dissipating stream energy. A river can develop a meandering course of low gradient without having to transport large quantities of sediment by downcutting. Streams transporting little bed-material loads are relatively narrow, deep, and sinuous. Some rivers transporting only very fine sediment are very straight (low sinuosity) [13].

From an engineering standpoint, the only independent variables that need to be considered for defining channel pattern are: (1) discharge, (2) valley slope, (3) material in the bed and banks, and (4) man's activities [14].

The centrifugal force in the bend causes a transverse water-surface slope and helicoidal flow in the bend. These transverse gradients induce velocity components toward the convex bank having a magnitude of about 15 percent of the average channel velocity; concentrations of bedload are swept toward the convex bank to be deposited as point bars. Scour in the bends causes migration of the entire pattern in a downstream direction and sometimes in a lateral direction. Recorded downstream meander pattern movements have been as great as 2500 ft per year in alluvial rivers. Also, much of the material eroded from the concave bank is deposited in the crossing and on the point bar in the next bend downstream [15].

In steep, confined mountain streams, an alternating series of deeps and shallows, related to bends and crossings in freely meandering channels have been observed. Leopold reported the alternating pools and rapids in the Colorado River through the Grand Canyon [16].

Straight Pattern. Even when the channel appea straight, it is unusual for the thalweg not to wander back and forth in a meandering fashion. Even in straight channels, alternate bars develop [8]. Stee confined streams, fairly straight in alignment, deve op pool and riffle patterns with spacings very comparable to the spacings of pools and crossings in similar-size, freely meandering streams. "Extremely short segments or reaches of the channel may be straight, but it can be stated as a generalization that reaches which are straight for distances exceeding 10 times the channel width are rare" [17].

A straight pattern was defined as one having a sinuousity or tortuosity ratio of less than 1.5. Long reaches (up to 2.5 miles, 30 times river width) on th North Loup and Middle Loup River with a sinuosity index of less than 1.01 are fairly common. The straightness of the Loup River reaches may be exceptions [6].

## Streamflow and Slope Prediction

A recent study, completed by the author, has provided prediction equations for average daily discharge and river slope from river pattern characteristics. In the intermountain regions of Colorado, Wyoming, and Montana, 11 freely meandering rivers were selected. The pattern (planimetric shape) characteristics of each river were determined from 7.5 min quadrangle sheets using a coordinatograph and a CDC 6400 computer. The correlation coefficient between average daily discharge and mean radius of curvature was 0.88; the correlation coefficient between river slope and tortuosity was 0.73 [1].

The rivers investigated had average daily discharges ranging from about 30 cfs to about 1000 cfs, slope ranging from 5 ft per mile to 69 ft per mile, and drainage basin areas ranging from about 80 to 4000 square miles.

River pattern is a characteristic that can be easily recognized from almost any form of imagery or photography taken in preferably a near vertical direction (o. with known orientation) and with some estimate of imagery or photographic scale. River pattern is a characteristic that could be automated at the sensor output for subsequent use in routine logic decisions. Line scanner output, for example, can be programmed to recognize the water-land interface and subsequently define the river pattern. Studies to date indicate a need for additional work to refine the process of riverflow and slope prediction, preferably in the automated fashion [18].

## Other Characteristics of Rivers

Studies to date can provide estimates of riverflow and slope from pattern characteristics of some intermontane regions of the Rocky Mountains. Refined prediction equations of a multivariate nature need to be established between the pattern and the hydraulic characteristics for rivers in a variety of fluvial-geomorphologic environments. Orbital altitude photography will provide an economical way to develop and utilize these relationships.

Many additional characteristics related to the riverbed may be interpreted from high-quality satellite imagery. The author has listed 10 categories of particular importance to river engineers:

1. Sediment transport processes. Relative suspended sediment concentrations in rivers may be interpreted readily from color infrared photography taken from an aircraft platform (Fig. 2). The Gemini photography also demonstrated this distinctive tone change, where dark-colored bodies of water indicate relatively clear water and blue tones in water indicate the presence of suspended sediment. Using this interpretive key, a person acquainted with rivers can determine where erosion is occurring and trace the transport path. Recent remote sensing studies on the lower Mississippi River using color infrared have utilized this technique for identifying areas of erosion, describing flow patterns, and locating sections of the river where flow separation is occurring.

2. Flood plain vegetation surveys. The flood plain soils are generally very fertile and consequently, much agriculture is practiced on flood plains, particularly in the arid and semiarid parts of the world. Vegetation of a variety of types, including beneficial and nonbeneficial vegetation, consumes a considerable amount of the ground water located in the underground reservoir immediately beneath the flood-plain areas.

Particular attention must be paid to the encroachment of salinity problems induced by the proximity of the water table, poor drainage characteristics, and reuse of the water itself. Phreatophytes, that is, nonbeneficial plant life, can consume considerable amounts of ground water. In the western part of the U.S. there have been programs to attempt to eliminate this undesirable type of vegetation and consequently save some water in the process. Color infrared photography again has proven quite beneficial for evaluating plant species, and identifying certain types of plant stress (Fig. 3). The plant vigor is often related to the proximity of the water table.

3. Flood prediction and damage evaluation. Throughout the entire world excess volumes of water cause considerable damage to life and property. The ability to track a flood crest via the satellite observations would be tremendously beneficial. A large proportion of the population both here in the U.S. and abroad live immediately adjacent to large rivers and are particularly vulnerable to unexpected high flows in a river (Fig. 4).

4. Soil classification. The ability to classify soils for agricultural purposes and to locate gravel deposits commonly found in the flood-plain areas is of considerable importance. Procedures have been developed in terms of photointerpretation for these applications but a good amount more must be done and would be very practical with more sophisticated sensors and procedures. Gravel deposits, for example, are becoming a rather scarce commodity, and they are often classified as valuable mineral resources in certain areas (Fig. 5).

5. River navigation. A considerable amount of our commerce here in the U.S. depends on very economical transportation on our major river systems. A continuing ongoing process is the maintenance of these navigation channels (Fig. 6). An improved procedure for locating the thalweg (or the position of the deepest part of the stream) would be very worthwhile. A person acquainted with rivers and fluid mechanics can interpret the location of this thalweg from color infrared photography, for example. Recent studies at Colorado State University also indicate that thermal infrared imagery may be used, in some cases, to indicate the major channel in the river. In addition, space photography can provide an excellent monitoring technique for managing river traffic.

6. Water depths in clear water. Certain films are now available which allow one to record the bottom detail of near-coastal areas or of clear, inland streams to considerable depths. Studies completed in Montana this past year, using color infrared

photography, allowed perception of the detail of the channel bottom and bars for a particular clear-water river.

7. Drainage net pattern. This is another planimetric feature that can be quite easily extracted from either good quality imagery or photography from space (Fig. 7). Information about the drainage net pattern can help one to better understand discharge characteristics of streams. Work is currently being undertaken at Colorado State University in this respect.

8. Water resource management. The ability to observe very large areas can be helpful in connection with recording precipitation patterns, including both rainfall and snowfall, and for the subsequent use of flow prediction in streams (Fig. 8). Historically, flow prediction, at least in the western part of the U.S., has been based on snow surveys taken periodically during the winter months. Ordinarily these historical statistical procedures have provided a fair prediction for use in planning for reservoir fillings and withdrawals. However, this spring on the North Platte River Basin in eastern Wyoming and western Nebraska, considerable damage was done to the flood-plain areas. This was because of the fact that excess runoff from the high mountains forced unusually high releases from the impounding reservoirs in order to accommodate the new runoff from the snowfields.

It has been evident for some time that improved methods for flow prediction are necessary for optimum management of our water resources. In connection with the normal irrigation practices, the water resource managers need information about water use patterns in order to make appropriate releases to satisfy demands. Satellite observation could provide this valuable mapping of water use patterns. In addition, from the appearance of certain crops, the water use manager can estimate irrigation scheduling.

Another factor in water resource management, of course, is the aspect of pollution. Large pollution spills can be very hazardous to downstream users. Oftentimes these spills are noticed before they become a part of some organization's consumption, but certainly an early warning system concerning pollution spills would be very important. During excessive rainfall periods streams may become polluted because of runoff from bordering feedlots (Fig. 9).

9. Channel changes. The Gemini photos of the lower Mississippi River are of particular interest to the people concerned with the maintenan of navigation and flood control in this major river. Certain portions of the river have been longtime problem areas and, in the case of several colleague familiar with river mechanics, a glance at some of these photographs can quickly indicate why these particular areas are causing difficulty. A river tends to meander, and wherever man has affected this normal meandering pattern he can expect considerable difficulty in maintenance of the channel.

10. Increased knowledge to mankind about river systems. Man knows very little about the behavior of the total river system primarily because he has had only a chance to look at pieces of any particular river system. Observations from an orbital platform using a variety of sensors can materially increase man's understanding of this complex system. It is prohibitive from the data magnitude standpoint to try to record everything about all river systems. On the other hand, orbital altitude imagery and photography can pinpoint those areas where additional investigations can be most economically achieved. Certainly aircraft and in some cases extensive ground data collections are a vital part of this overall look [19, 20].

## Conclusion

River pattern definition from orbital altitudes can materially increase mankind's understanding of river systems throughout the world. Quantification of river pattern can be accomplished for estimating discharge and river slope. High-quality imagery and photography can provide a unique, overall view of sediment transport and deposition processes in streams, delineate flood plains and provide vegetation surveys, help predict and evaluate flood damages, monitor and identify river traffic, and aid materially in precipitation surveys for optimum water resource management.

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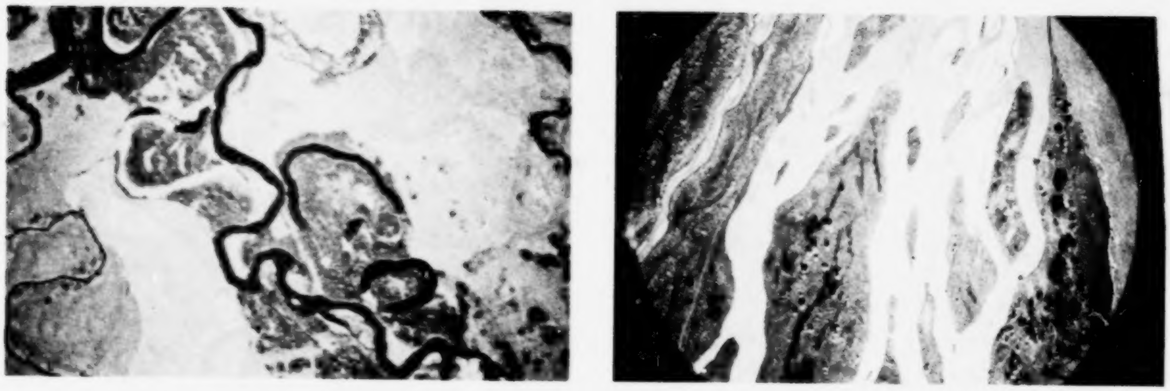

Meander pattern/cutoff oxbows

Braided pattern

Figure 1. River patterns.

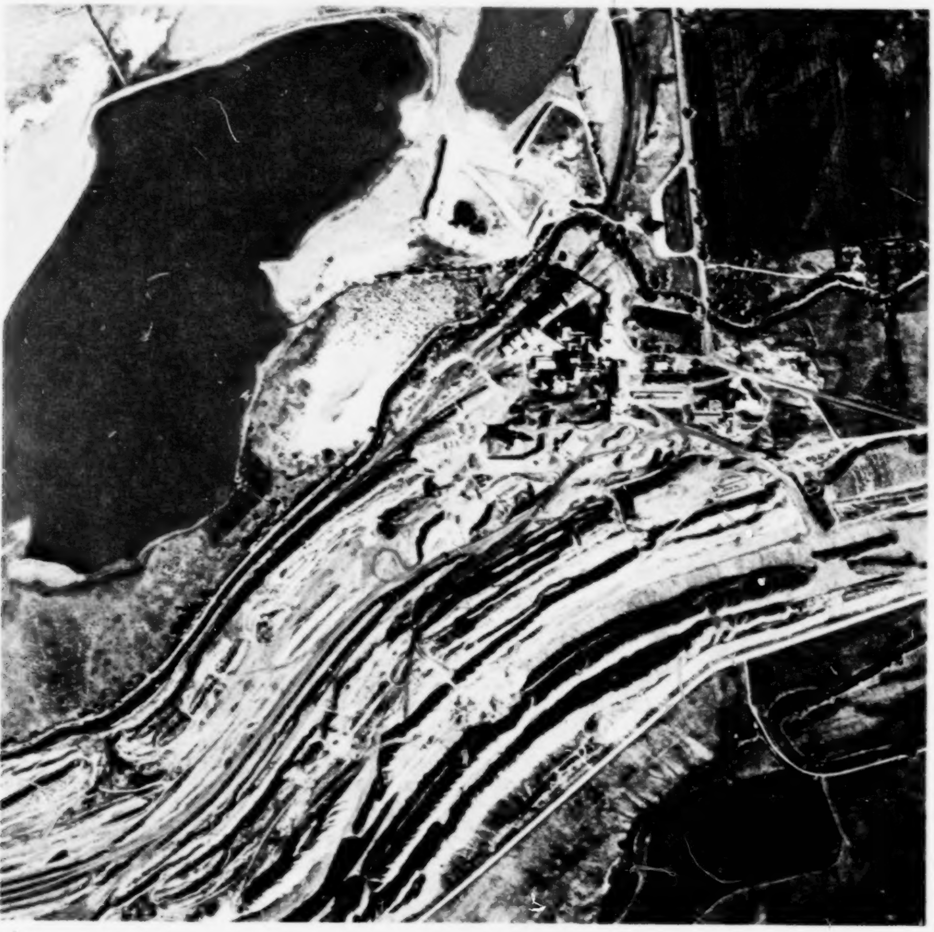

Figure 2. Internegative print from Kodak Aerochrome infrared film 2443 (cement plant near Fort Collins, Colorado).

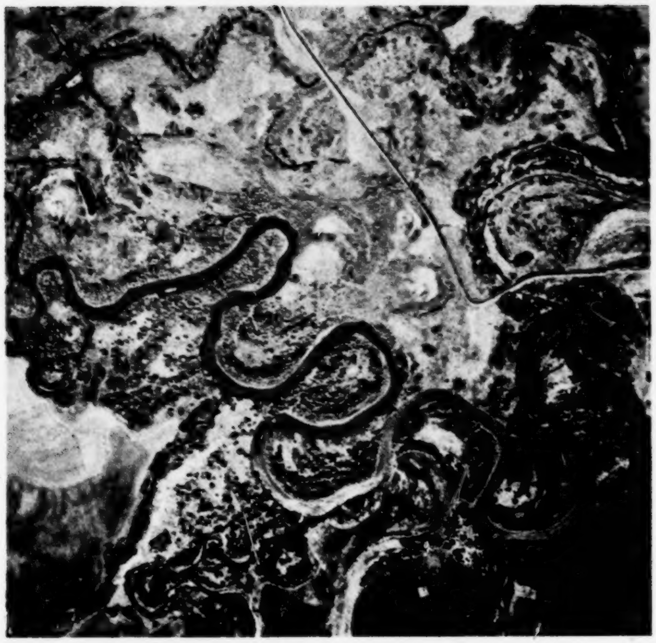

Figure 3. Internegative print from Kodak Aerochrome infrared film 2443 (cement plant near Fort Collins, Colorado).

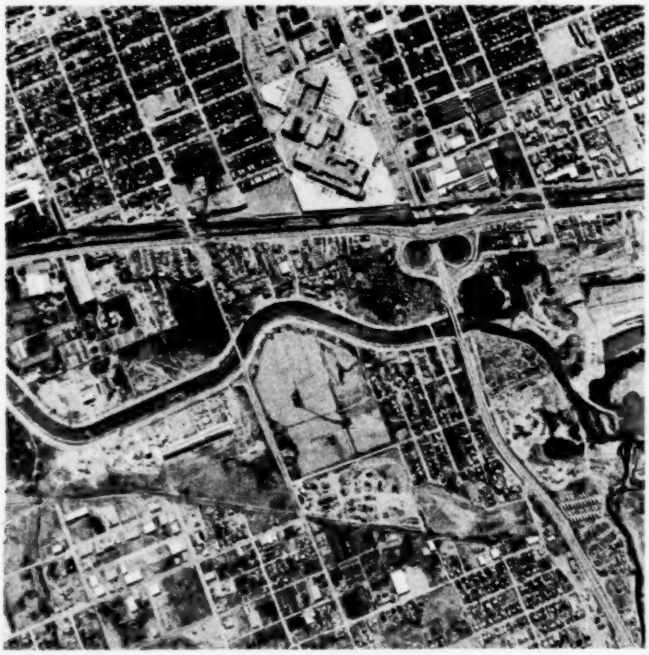

Figure 4. Print from Kodak Aerocolor negative film 2445 (South Platte River in Denver, Colorado).

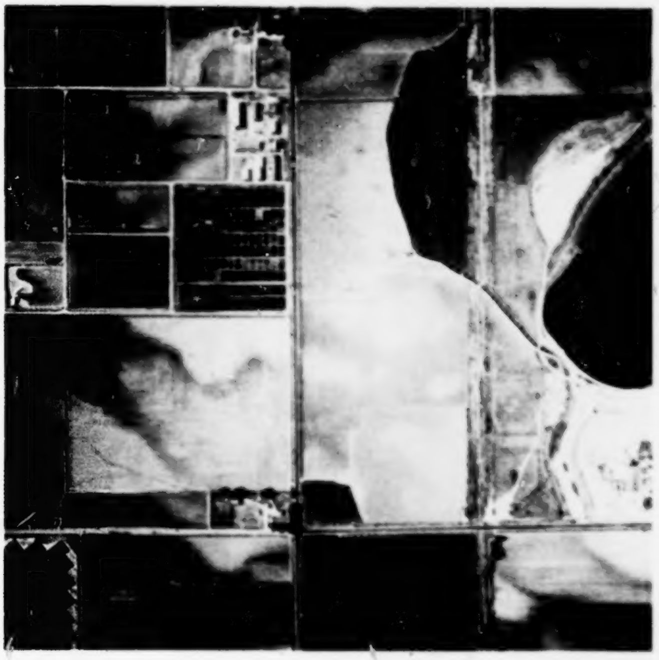

Figure 5. Ektachrome RC print from Kodak Aerochrome infrared film 2443 (area near Fort Collins, Colorado).

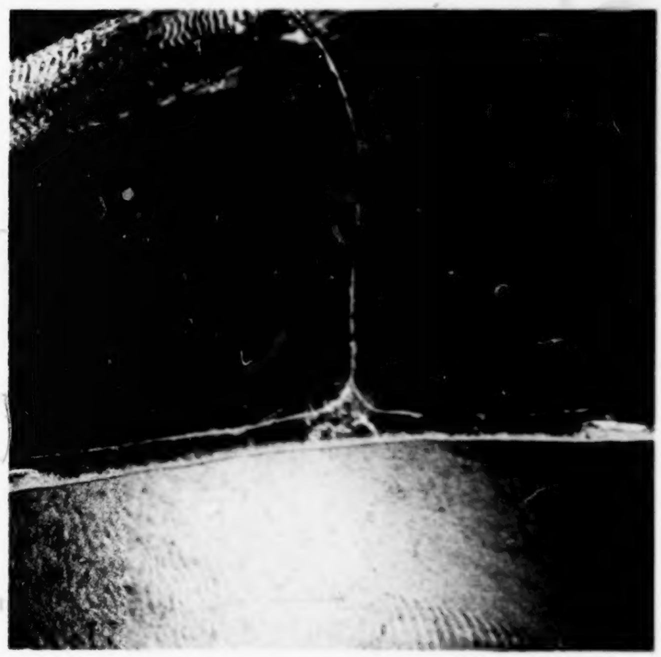

Figure 6. Ektachrome RC print from Kodak Aerochrome infrared film 2443 (Mississippi River near Vicksburg, Mississippi).

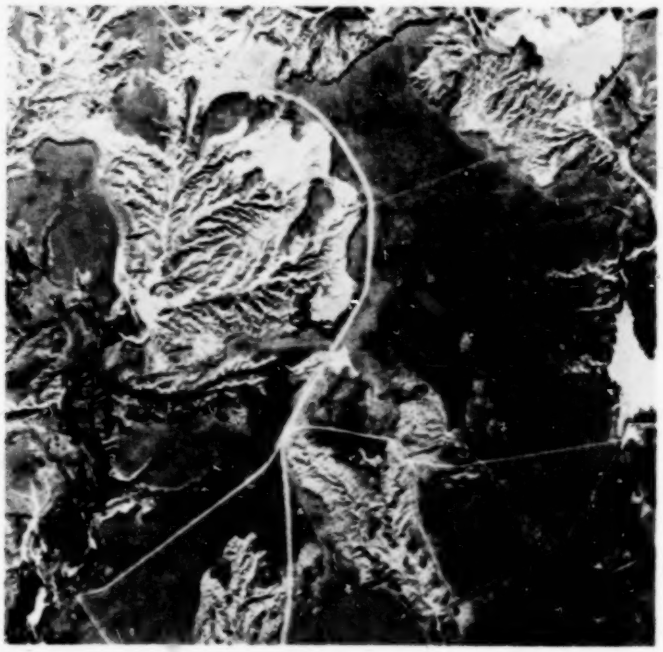

Figure 7. Special process print from Kodak Aerocolor negative film 2445 (area near Lusk, Wyoming).

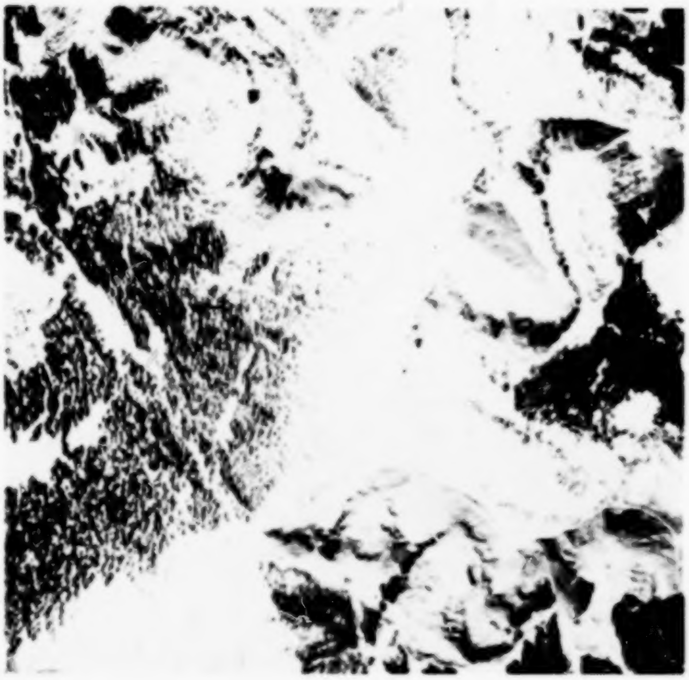

Figure 8. Ektachrome RC print from Kodak Aerochrome infrared film 2443 (Wolf Creek Pass area, Colorado; photography obtained in conjunction with Marshall Space Flight Center).

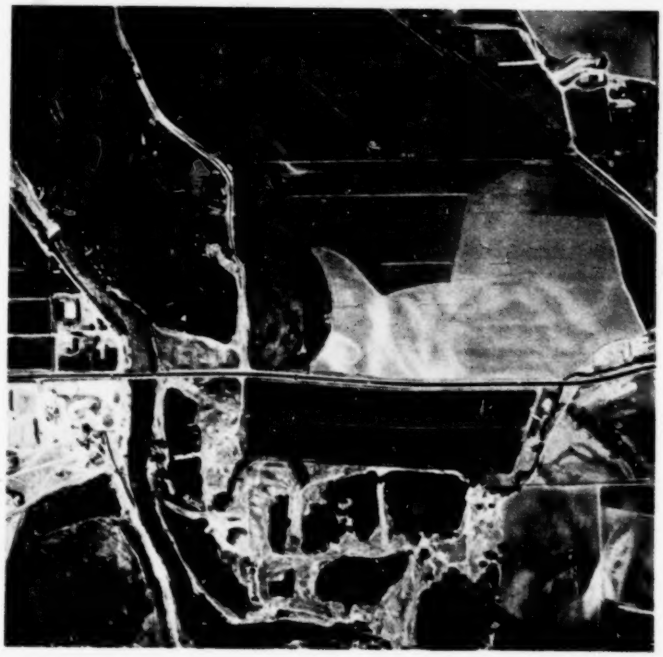

Figure 9. Ektachrome RC print from Kodak Aerochrome infrared film 2443 (area near Fort Collins, Colorado; note feedlot adjacent to stream).

# A LITTLE BEYOND TOMORROW

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It is indeed appropriate that this Space Congress is being held in Huntsville, because it was here, as you all know, that we spawned the propulsive power which man used to fly in space and land on the moon, and without which we might still be earthbound. What is earthbound about Huntsville, though, is the fact this fine city is firsthand evidence that the bulk of space dollars has been spent right here on the ground. With all due respect to my vegetarian friends, it has worked out a lot better than watercress.

But I do not want to dwell on history with which you are familiar. I want to talk about the future, about a period beyond the noise and trauma of today when space will directly affect our lives in a daily manner. To bring it into sharper focus, we are at the point where there will soon be more people on earth than in heaven and hell combined. So the space program has a particular challenge to face in helping make sure that we do not unwittingly swap places with the hereafter.

In many ways the space program can be likened to a teenager — one beset with the awkwardness of public apathy and the acne of reduced funds. This teenager has some other problems, too. At one point in his life, much like other youngsters, he knew it all. The fact that he scored on his first date to the moon frightened off the girls and the public. Now they are reluctant to go steady with him, even though he is envied by some of his contemporaries. This reluctance is aggravated by his ability to consume a lot of bread. He stands in the unenviable position of having so much to give and yet he faces the stark danger of becoming impotent before reaching his twenties. Our space teenager has not been staying home. He has been on an international tour, some of it successful. However, there are a lot of people in the world who look at him only in terms of a trip to the moon, and many of those think it has been a bummer. Lest I give you the impression that all is bleak, let us consider some fundamentals. Like other teenagers, this one has to leave the warm shelter of the sixties and learn how to live in a competitive world. He must find his own way in a society that is making a quantum break with the past.

Many of us feel very strongly that the space program will affect our lives in a more direct way than it has thus far. I, for one, believe that space will become an integral part of us and we of it. Space must do this, or it may not survive as a broad-based activity. It must become a part of our everyday lives, or, perhaps, remain at best a research and development pursuit. When addressing the future, it is a well-known fact that we scientists and engineers have a strong tendency to overestimate what we can do in the short term and underestimate what can be accomplished in the longer term. For instance, we can get very optimistic about meeting a rather tight launch schedule, say for the next satellite in a given program. Yet, on the other hand, there are many prominent technologists who did not think man would land on the moon until the seventies or eighties. When we deal in the near term, we almost always have some specific project in mind that somebody is trying to sell, and there is always a tendency to push the immediate accomplishments too hard. In contrast, to delve too far into the future to justify our efforts in space may once have been an acceptable approach, but, with so much of science fiction already an accomplished fact, things like colonization of the planets have about as much impact as watching paint dry. Therefore, I would like to concentrate on the time "a little beyond tomorrow," where we can deal with possibilities that are based on research and technology already in progress. They do not seem to get the proper attention, even though I think they are the strongest rationale for our current space efforts.

First, I want to talk about one of the oldest areas which is benefiting from space technology, that is, meteorology. Weather satellites were among the first spacecraft put into orbit in the early sixties. They have been eminently successful and yet, we cannot honestly say they have revolutionized forecasting. Why not? Simply because, despite our experience, we are still in the early stages of this business. What accomplishments have we seen? Probably the major one is disaster prediction. The examples of successful hurricane detection and tracking by satellite with the attendant advanced warning for saving lives are now commonplace.

So far, these satellites have probably helped other countries more than ours in predicting the weather. Australia and Chile can come up with 1- or 2-day forecasts, which they could not do as well before, by using information about conditions in the oceans that lie in the path of their weather.

If we look ahead, we are on the verge of a significant breakthrough, because we are going from a situation where we receive pictures from space to one where we are getting data that can be fed into computers. In other words, we will be probing the vertical dimension of the atmosphere from space. This will give us the ability to make better mathematical models of the world's weather and to speak to computers on their own terms. Ultimately, as we get to understand the dynamics of the atmosphere, we should be able to solve the problem of the general circulation of the atmosphere. Then we can expect to achieve an accurate forecast about 2 to 3 weeks in advance. And that is where I believe our space meteorological efforts are taking us.

The next aspect I want to get into is to look beneath the weather at our earth, in other words, the Earth Resources Satellite. A lot has been said and written about this subject, perhaps much of it overselling in the short term. I would not want to see promises of benefits from our very first Earth Resources Technology Satellite (ERTS) be those that will only come from several years of experience in this vital and emerging field. The nub of the matter is that the world's food and other resources are in critical supply; and for the first time, we are going to have multispectral measurements from space that will give us an idea of where we stand. The interest is fantastic — for example, NASA has received some 7000 proposals for experiments involving the ERTS program. These range from studying crop diseases and ocean conditions to mapping urban areas and getting information about snow and ice cover as a means of locating water sources. Also, what better way will there be to monitor the pollutants in our environment!

As these programs progress, and the countries of the world are ready to take action, we will have new guidelines to help us decide where crops can be grown more efficiently, how to manage our precious water resources, our forests, our land, where to better find new resources and fishing grounds, and what we need to do to clean up our atmosphere.

Now, let me turn briefly to education and knowledge and how space is playing an important role here. We all know of the impact that the space program has had on school curricula, especially in mathematics and the sciences. But, not as much is known of the new educational technologies stemming from space sciences.

Brazil, for example, is planning a direct-broadcast educational television system that would reach more than 100 000 schools. In some cases, as many as six classrooms with television monitors would be used in each school. Another possible use of the system would be adult education during the evening hours. In the U. S., there are plans to beam educational television via satellite to rural schoolrooms in Appalachia. The intent in all such programs is to get the best educational talent a country can find to reach the maximum number of people. In the future, computer-aided education would enable a child at his desk to tap into knowledge sources anywhere, instead of relying just on the school library. These "electronic encyclopedias" will give us the means so that by the year 2000 every person in the world, wherever he may be, could have access to at least a high school education.

Transportation is another vital area that needs to benefit from space work, because our mobility as individuals is threatened in a world that is becoming more densely populated every day. There are some obvious problems where space technology is the only valid solution, such as air traffic control. Today, airplanes fly over the oceans with lateral separation standards of 120 miles and 20 min flying time in-track.

Sometime in the next decade or two, they may be able to reduce these standards to, say, 30 miles laterally and 5 min in-track so that they can fly more safely with the denser patterns that will result as air traffic gets as packed as some of our highways. Over land, air controllers will be locating planes within 50 ft and 1.5-mile airspeed. Down on the ground, we may see police cars, taxicabs, and other fleet vehicles controlled through pinpoint location provided by satellite.

Up until now, I have been talking about areas in which a lot of basic work has been done, and there are programs underway that give us some good ideas of how the future might turn out. However, there is a concept that is still in its infancy, called space manufacturing, that may ultimately show the most promise, although it will require new programs to get us where we want to go. It is possible that the weightlessness and near-perfect vacuum of space could serve as the basis for manufacturing facilities that will give us materials and products of a quality unattainable on earth, except at prohibitive cost. Things like purer vaccines and superior crystals are examples of prime possibilities. It has been estimated that by the end of this century the total value of electronic materials and biologicals manufactured in space could run upward of $50 billion.

In the last 20 years of so, we have achieved an order of magnitude of purification in some of our biological materials. This is, perhaps, a practical limit achievable on earth. Yet, you and I still get undesirable side effects from some vaccines and medicines. Therefore, space may afford us the opportunity to reach another order of magnitude of purity without too much difficulty and thereby do away with these side results.

Another very interesting possibility has to do with the manufacture of high-quality magnetic oxide crystals in space. They would have little bubbles of gas moving around inside them, and would be used as memory storage units for computers. The increase in capacity and reduction in volume, in comparison with memory devices used today, would enable us to approach the capacity of the human brain. We might also achieve random access, like the brain has, in dredging up forgotten facts and figures. This development is being experimented with on earth, and the hope is that the better crystal structure we might attain by manufacturing in space would give us vastly improved results. Economically, today's memory devices cost between 5 cents and 1 cent per bit of information. The memory units of the future that I am describing would perhaps cost less than one-tenth of a cent.

Turning to more personal factors, not too much has been said about the community aspects of using space. In other words, man living with man, his attitudes, the haves and have nots, jobs, equal opportunities, and everything that goes to make up the whole sociological picture. Just a scant 10 years ago, live television could not be sent across the Atlantic. We were able to watch man's first steps on the moon 2 years ago. Now, communications satellites ride shotgun on the world and we can receive television anywhere. At the same time, about half of the international phone calls made today are going by satellite, and such usage is growing at a rate of about 40 percent per year. Voice transmissions on the earth sometimes have trouble reaching beyond the horizon, but, with relay satellites, we can cover nearly half the surface of the world at once. In the future, every person could have a portable telephone and could dial anywhere. Secretaries could type letters at their desks and, in a fraction of a second, they could be sent to their destinations by "Telemail." As the world continues to shrink, and each of us can watch and talk with his neighbor in real time, and vice versa, our expectations and attitudes will rise above national boundaries and what we have been taught in the past. So the sociological impacts will be staggering — I will not even venture a guess on the outcome.

In the field of health, space has already made many contributions. Electronic heart pacers, diagnostic sensors, and sight switches for manipulating wheelchairs are but a few among numerous examples of practical applications. In fact, the medical field has been one of the prime benefactors of the space program, because of the obvious necessity for providing life-support systems for our astronauts. In the future, we may have diagnostic and treatment centers in our own homes, tied into the medical facilities of the world by satellite. If we are ill, we can use our own time-sharing computer terminal to ask the outstanding minds of the medical profession what ails us and get a prescribed treatment in return. Whether this will lead to a generation of electronic hypochondriacs remains to be seen. Since diagnoses and treatments will not be restricted to physical ailments either, we may also have group therapy by satellite.

To sum it up, space surrounds all the earth so it is, indeed, a province of all peoples. Thus far, more than 70 countries are working with the U.S. on some program or other applying space to their problems. The United Nations is very active, too, particularly with respect to earth resources programs for developing countries. I submit that without the overview and the information that space can afford us, we cannot hope, literally, to survive on earth except at deteriorating levels. We are into the first payoff years of space, and we cannot stop now.

I want to close with several predictions. First, we are going to see a resurgence in favor of space and technology. Second, many of the benefits I have been discussing with you today will surely come to pass. And third, all of us, by virtue of our attendance at this Space Congress, qualify as salesmen for space. I can make these predictions with confidence because I have been assured by the chairman that most people will shortly forget what I said. Second, if I am wrong, a lot of other people are wrong, too. And, third, I may just damn well be right. If I am, then there is a great period ahead for all mankind.

# ADVANCEMENTS IN MEDICINE FROM AEROSPACE RESEARCH

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## Introduction

The world has recently viewed the dramatic successes of a space effort, which chose a difficult goal and then carefully developed the technology necessary to reach that goal. This paper discusses a program which is designed to find second applications in the field of medicine for the technology developed to achieve the nation's space goals. The program is the outgrowth of the congressional charter included in the Space Act of 1958, which directed NASA to find second applications for the technology which resulted from NASA's Research and Development (R&D) programs.

For several years NASA has sponsored a program which has, at its core, multidisciplinary teams of scientists and engineers called Application Teams. Such a team is located at each of three not-for-profit research institutes (the Research Triangle Institute of North Carolina, the Southwest Research Institute of Texas, and the Midwest Research Institute of Missouri) and one medical school (Stanford University). The teams seek to provide an interface between two diverse fields: aerospace and medicine.

The medical profession has awakened in the past decade to the need for advanced technology in medical research and health care. This awakening alone is not enough. Some effective avenues for the flow of information, ideas, and technology between the physical and medical sciences have been established, but more are needed. This program provides one such avenue.

## Methodology

"Technology utilization" is the term applied to the task of finding second applications for technology. Many of the methods for implementing the concept of technology utilization are largely passive in nature; passive, in this case, means the information is provided to those who seek it and thus the physician must understand the information system in order to use it. One of the unique features of the Application Team program is that the method is active. Active, in this sense, means that the problems and solutions are actively sought.

This search for problems is carried out by the members of the multidisciplinary team. Team members visit major medical centers (the National Institutes of Health and medical schools) where suitable medical problems are identified with the aid of a consultant. The consultant, a medical center staff member, helps to ensure that the problems selected meet certain minimum requirements. In general, our team accepts only those problems which (1) have no solutions available on the commercial market, (2) are discrete and can be defined in specific terms, (3) impede the progress of priority efforts of the physician, and (4) appear amenable to solution by aerospace-related technology. We impose these requirements because this program is designed for problem solving, not just for information searching.

If a problem meets these requirements, it is defined by the physician and team member during one or more meetings. Problem definition can probably best be explained by an example: arthritis is a crippling disease which can result in the destruction of the ball-and-socket joint of the hip. One method of treating this disease is to replace the human hip ball-and-socket joint with an artificial material. An orthopedic surgeon asked the team to find an improved material. The team quickly determined that the basic problem was that existing materials have inadequate friction and wear characteristics. The team looked for improved low friction-bearing materials which were biocompatible and not just for prosthetic hip joint materials. Thus, the search could be broadened to areas unrelated to medicine.

After a problem is defined, a solution is sought using several approaches. First, a computer search of the NASA document bank is performed, which covers approximately 700 000 documents. The bibliography and related documents are analyzed by the physician and the team member to determine whether an adequate solution is available.

A second approach used in finding solutions is to request suggestions from NASA personnel by circulating concise written problem statements to the NASA field centers. These documents are circulated by the Technology Utilization Officers (TUO) who are located at each center and who have a detailed knowledge of the research activities at their centers. The TUO provides a vital link between the teams and key NASA personnel.

A third approach is to contact field center personnel or NASA contractor personnel directly when the teams are aware that these personnel have knowledge about particular problems. These contacts, coordinated with each TUO, allow the teams to rapidly obtain advanced technological information.

After an idea or individual has been identified by these searching procedures, both direct and indirect contacts between physicians and NASA personnel are arranged. In the former case, physicians have visited NASA centers for discussions; in the latter case, the team members have provided the contact by visits and correspondence. Always the idea is to provide the physician with fresh insight into his problem from a discipline he does not normally encounter.

The team then acts as a catalyst to provide implementation of the ideas. Although the primary responsibility for implementation of the technology lies with the physician, the team assists in engineering consultation and in recommendations for ways of applying the technology. In addition, in a few instances, NASA has initiated feasibility studies directly when it is clear that no other avenues are open to the physician and when the necessary expertise is available only within NASA. At all times, the team feels that success comes only when utilization has occurred.

## Program Analysis

Because the transfer of technology in this active mode is a unique venture, significant efforts are made to analyze the transfer process so that improvements in transfer methodology can occur. The analysis phase of the program has disclosed several important facts about the problem of finding second applications for space technology. First, although the searching of document files is one key aspect of the program, it is not the most important aspect. Most information systems are designed to retrieve information directly related to a subject. Information that is indirectly related to a subject cannot be easily retrieved unless the searcher has some initial clues. A search for methods of rapidly heating blood, as an example, would probably not include semiconductor fabrication as a search term unless the searchers were aware that microwave heating is a vital aspect of semiconductor fabrication processes. Thus, search results are limited by the experience of the searcher.

The second important lesson learned from this program is that personal interaction is vital when two diverse disciplines are attempting to interact. In fact, disciplines do not really interact, but people do. This interaction between two diverse disciplines really results when two people sit down to talk. If we simply give a physician an engineering document, the results are usually quite low. Consider two examples: (1) The physician cannot begin to realize the significance of modern communications technology to his method of dispensing health care, and (2) the engineer cannot recognize the significance of his cryogenic technology to leukemia therapy until face-to-face and repeated interaction occurs. Personal interaction between all elements of the team program (physician, team member, and aerospace engineer) has been found to be of major importance for success.

## Examples of Results

In order to illustrate both the methodology and the results of the Application Team, examples of particular problems will now be discussed.

A prototype of a prosthetic urethral valve is shown in Figure 1. This valve is designed to meet the needs of patients with urinary incontinence or the inability to voluntarily control urination. In addition to the obvious social and hygienic implications of incontinence, this inability to control urination can result in tissue deterioration, infection, kidney damage, and eventually death. Previous attempts to solve this problem using electrical stimulation have not been satisfactory.

One problem in attempting to use a valve in the urinary system is that urine causes an incrustation that fouls most valves. This problem was posed to NASA engineers at Lewis Research Center who proposed the use of a flexible membrane valve. A team engineer proposed a check valve that, together with the bulb shown in Figure 1, forms a bistable valve which controls the urine flow. This device is now undergoing testing in experimental animals, and if it is perfected, an estimated 15 000 patients per year could benefit from this device.

The next example concerns the need for careful monitoring of leukemia patients who, not uncommonly, die of shock — as opposed to some cause more directly related to the proliferation of white blood cell forming tissue. In order to prevent these deaths, the National Cancer Institute asked the team to find a means of monitoring blood pressure without significantly disturbing the patient. Conventional blood pressure measurements require an occlusive cuff which is clearly unsuitable for frequent, round-the-clock monitoring.

A direct contact with NASA's Ames Research Center revealed that an ear oximeter had been developed for measuring oxygen content of the blood of astronauts in ground testing. This device, shown in Figure 2, was also sensitive to relative changes in blood pressure. Although previous ear oximeters required that blood flow in the ear be occluded in order to measure blood pressure, this new NASA development removed this requirement and the resulting discomfort. At the present time, the NASA ear oximeter is undergoing clinical trials at the National Cancer Institute. Successful conclusion of these trials could result in savings of hundreds of lives annually.

A third example of an application of aerospace technology resulted when the Environmental Protection Agency (EPA) wanted to study the effects of low levels of carbon monoxide on automobile drivers. A search revealed that a NASA scientist at Langley Research Center had developed an instrument, shown in Figure 3, which measured the coordination and reaction time of astronauts exposed to contaminants in spacecraft. This instrument was loaned to EPA and is now being used for the planned study. Although the new application of the equipment is not significantly different from the basic NASA use, it is interesting to note that EPA had planned to develop such an instrument on contract so that a significant savings in tax dollars resulted.

A fourth example is shown in Figure 4. This is a radiation dosimeter probe, developed under NASA sponsorship for nonmedical purposes, and is now being used to measure the radiation level absorbed around cancerous areas in order to determine the position of administered radioisotopes. This allows more precise definition of cancerous areas and prevents damage to surrounding healthy tissue.

The final example of a transfer concerns the need for an improved electromyographic muscle trainer. When muscles of the hand become damaged or atrophied, an electromyographic muscle trainer is employed to determine whether or not a specific muscle is being used. The trainer consists of two electrodes, an amplifier, and a speaker which allows the patient to hear when a specific muscle is being used, but the bulky electrodes previously employed were too large for proper results.

Figure 5 shows the use of small electrodes devised from NASA-developed spray-on electrode formulations. With these electrodes no further attachment mechanism is needed for the wires, and the electrodes provide extremely satisfactory results. The improved access to the muscle being exercised permits improved rehabilitation procedures for a significant number of patients. The technique is already in use in several rehabilitation centers.

## Conclusion

This paper has described a new and exciting approach to the process of finding new applications for space technology. NASA has taken the lead in implementing the concept of technology utilization, and the Technology Utilization program is the first vital step in the goal of a technological society to insure maximum benefit from the costs of technology. Experience has shown that the active approach to technology transfer is unique and is well received in the medical profession when appropriate problems are tackled. The problem-solving approach is a useful one at the precise time when medicine is recognizing the need for new technology.

It is significant that the decade which heralded the space age is also the decade that signaled the awakening of medicine to the need for technology. Whether the coincidence is directly related, indirectly related, or unrelated can be argued by philosophers. But this simultaneous occurrence cannot be ignored, and this program is one step in the many that are needed to fulfill medicine's needs. Thus, the Application Team program clearly fits the purpose of this conference which is to discuss "Space for Mankind's Benefit."

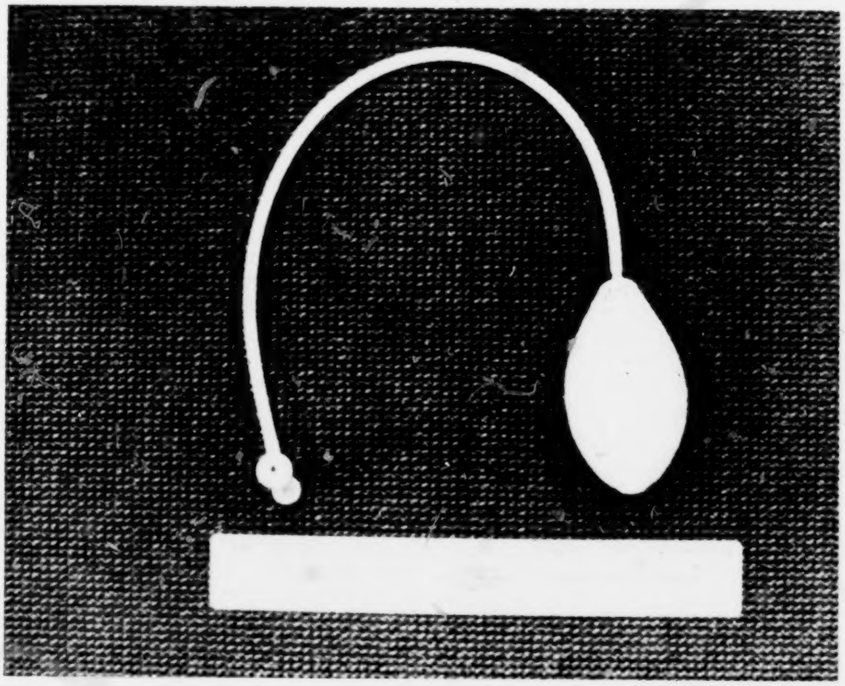

Figure 1. Prototype prosthetic urinary valve.

Figure 2. Ear oximeter.

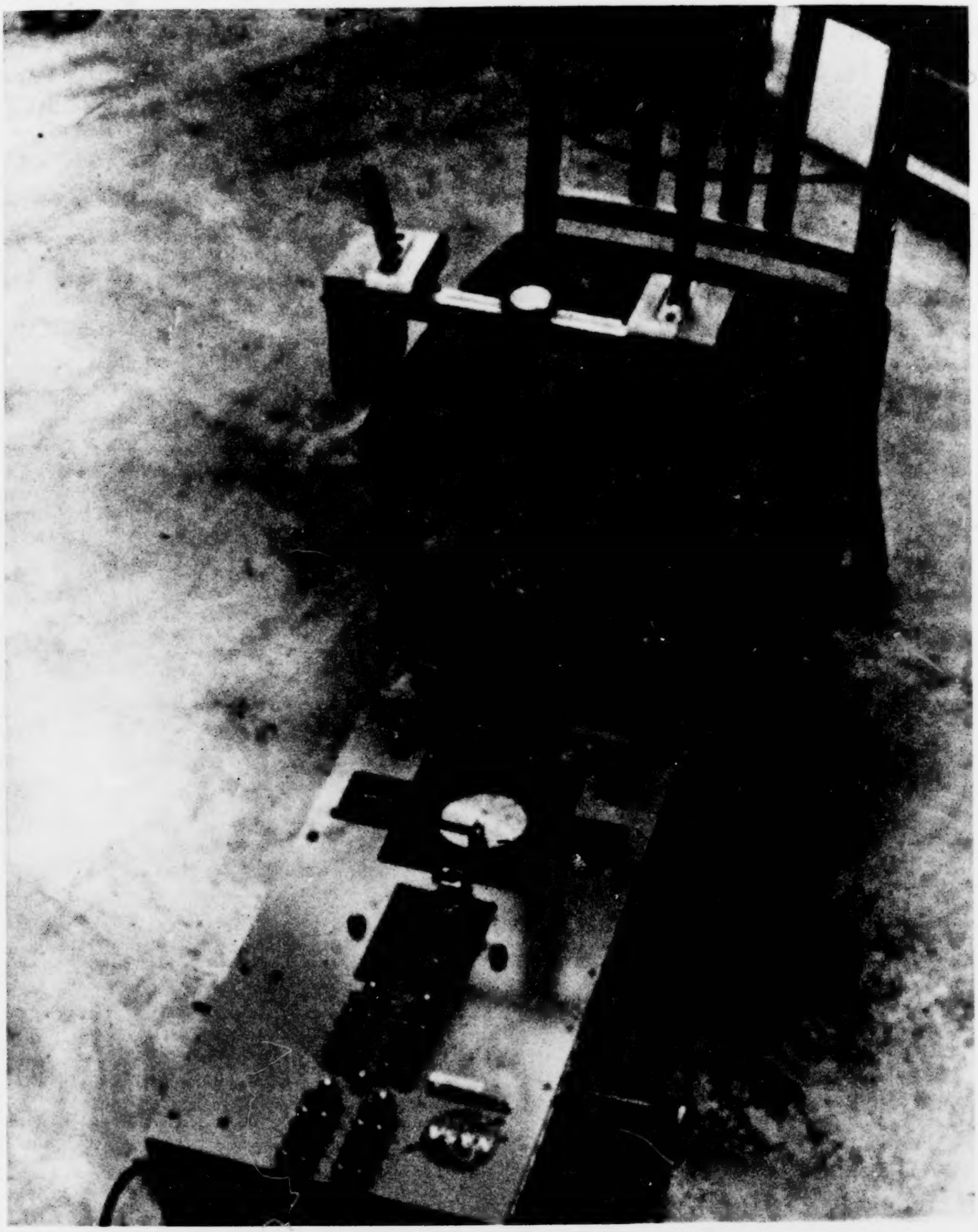

Figure 3. Complex coordinator.

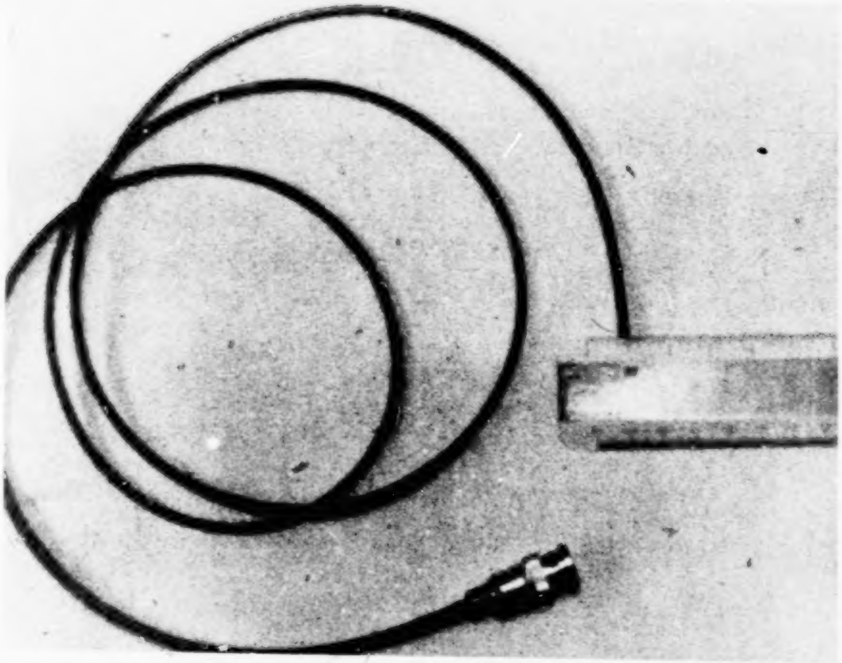

Figure 4. Radiation dosimeter.

Figure 5. Electromyographic electrodes.

# DOMESTIC APPLICATIONS FOR AEROSPACE WASTE AND WATER MANAGEMENT TECHNOLOGIES

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## Abstract

The tools for solving many of today's pollution problems have been developed by aerospace technologists. Of major importance are the approaches used to identify very complex problems, to select the best solution, and to implement vast programs. None of these approaches or technical processes is unique to the aerospace community. They have, in fact, been borrowed from government, academic, and industrial sources, refined and repeatedly used in solving aerospace problems and are now ready for general use in solving today's pollution problems.

This paper explores some of the aerospace developments in solid waste disposal and water purification, which are applicable to specific domestic problems. Also, the paper will provide an overview of the management techniques used in defining the need, in utilizing the available tools, and in synthesizing a solution.

Specifically, several water recovery processes will be compared for domestic applicability; e.g., filtration, distillation, catalytic oxidation, reverse osmosis, electrodialysis, etc. Also solids disposal methods will be discussed; e.g., chemical treatment, drying, incineration, wet oxidation, etc. The latest developments in reducing household water requirements and some concepts for reusing water will be outlined.

## The Need

In 1872 London, the Government's Metropolis Water Act called for inventions to solve the "shocking wastage of water that was going on in the lavatories of the metropolis." The solution was the Valveless Water Waste Preventer patented by Thomas Crapper. As a reward, Crapper was appointed Sanitary Engineer to His Majesty and created a long- and little-known series of inventions which evolved into the commode and sanitary drain designs as we know them today. As today's water supplies become more limited, it is again time to call for new ideas to conserve water. Do you realize that 45 percent of your household water usage goes for flushing the commode and only 5 percent for drinking? What a waste of a valuable resource!

Since we are talking about handling of wastes, do you realize that a cow generates as much excreta as 16 humans, and that the wastes from livestock and poultry production alone are 1.7 billion tons per year or 4 times the amount of waste and trash produced in the cities? The problems of pollution and conservation span the full spectrum from urban domestic dwellings to rural farms. We are continually bombarded with statistics to show the complexity and magnitude of the problem; however, it does not really hit home until you are told to boil your water before it is safe to drink, or you are stopped from building your new home because an acceptable sewage disposal method is not available.

The aerospace community is being challenged by nearly everyone with the now standard statement, "We can put a man on the moon, but we cannot..." The nation's space activities and earth environmental problems have many areas of commonality, a few of which are both very complex, technical problems, and there are many thousands of skilled engineers and scientists solving them. The biggest difference is that putting men on the moon involved the actual landing of a few dedicated men, while improving our environment requires the commitment and support of millions of people with a diverse view of priorities.

This conference, "Space for Mankind's Benefit," is focusing priorities and depicts many sophisticated systems developed for space or using space to benefit man through better weather forecasts, communication and navigation, and development of natural resources. A more mundane topic is space technology developed for waste management and water recovery, which are applicable to domestic uses. When we think of the earth as a large spaceship, then the relationship of the space technology (or tools) to earth's ecology becomes more apparent.

## The Available Tools

The tools developed to solve very complex aerospace problems are not unique to the space business. In fact, they have been borrowed from government, academic and industrial sources, refined and repeatedly used. Two of these management sciences, namely, systems approach and optimization techniques, are worthy of more detail.

### SYSTEMS APPROACH

The systems approach is merely a means of providing a structured consistency to a program. The complexities of the space program have necessitated the development of this approach. The complexities of the pollution problem on earth are even greater than that required to put a man on the moon. However, now the tools are available to solve the overall problem and the individual problems of each community and household.

Basically stated, the systems approach is characterized by the following ground rules:

1. Start at the highest and most general echelon of cognizance to determine the boundaries of the overall system

2. Define the systems (concepts) and processes in stages of increasing detail, translating functional requirements into hardware requirements

3. Do not prejudge solutions; any solutions in mind should serve as guides, rather than points of departure, in the planning process.

Figure 1 gives a detailed treatment of the structure of the systems approach by highlighting the four principal states or steps involved:

1. Translation
2. Analysis
3. Tradeoff
4. Synthesis.

The translation, or initial formulation of the problem (need), is an important step that sets the course of all the work that will follow. Translation includes the interpretation of objectives, and, in addition, all recognized constraints on the problem solution criteria shall also be determined. Some categories of constraints, such as timing and policy, may also be used as selection criteria in developing the future program plans. The difference between these two uses is that constraints are generally applied as absolute limitations, whereas selection criteria are applied in the cycle to determine the relative merit of possible approaches. During the cycle, a number of feedbacks may be required, as shown in Figure 1, to improve and reevaluate the output.

### OPTIMIZATION TECHNIQUES

Optimization is the process by which the best system is identified for the predetermined criterion of the study. A typical method of effectiveness and cost modeling is shown in Figure 2.

A general approach or model to system optimization is summarized in Figure 3. It can be seen that optimization is a reiterative process consisting of the following steps:

1. Design several concepts that satisfy the operational requirements and constraints

2. Compute resultant values of effectiveness and resource use

3. Evaluate these results and make generalizations concerning appropriate combinations of design and support factors, which are then reiterated in the model.

This then is the general method of attacking very complex problems. Some of the tools are the actual hardware developments.

## AEROSPACE HARDWARE DEVELOPMENTS

A vast amount of new technology is being developed for advanced space missions where waste management and water recovery are key elements to a successful mission. Ecology-minded citizens are now realizing that the earth is not dissimilar from a space vehicle and that many of the space developments are also applicable to earth-type problems. Even the space-developed zero-gravity operational technology is found useful in designs for ship systems which must operate during extreme pitch and roll conditions.

Most of the NASA hardware developments have centered around low water use devices and water recovery. However, many other ancillary developments have also resulted from a quest for safer and more acceptable systems; e.g., bacteria sensors.

### Low Water Use Devices

Commode. The recent development of the fourth generation Hydro-John (under NASA Contract NAS 9-9741) has shown that flushing and cleanliness can be achieved with less than 1 lb of water compared to 40 lb for a typical earth commode flush (Fig. 4). A second advantage of the Hydro-John is that wiping tissues are not required. This is an advantage for remotely located toilets where maintenance is a problem; also the cost saving on the tissue may be more significant than the water saving. If water for flushing is not available, the Dry John (Fig. 5) has been successfully used for over 600 man-days in chamber tests. This unit collects, stores, and vacuum dries the wastes. It is discussed further on page 224.

Urinal. Probably the greatest waste of water is committed when the conventional commode is flushed after urination. This technique uses 40 lb of water to flush away 1 lb of liquid. Commodes with a "half flush" are in use in Europe. Separate male/female urinals have been designed for space use which have a flush capability requiring only 0.25 lb of water.

Showers. The shower configurations being tested at NASA each show a significant reduction in water requirement. Typically, a shower requires less than 10 lb of water compared to the conventional 160-lb requirement. The aerospace shower features temperature control of both the water and the air in the shower enclosure. These features alone would save a significant amount of water in the home since much water is wasted in achieving the proper water temperature for showering and only a few commercial models provide for stopping and starting the waterflow without the possibility of being scalded or chilled.

Clothes Washer. Conventional clothes washers generally require over 300 lb of water heated to approximately 120°F, and in the household of a large family, the automatic washer is used at least once a day. NASA is developing a low water usage washing machine. General Electric has developed and tested a washer which uses only 1 lb of water per pound (dry weight) of clothing to be washed.

Dishwasher. The development of dishwashers has not stressed conservation of water. Cleanliness of the dishes is the main goal, as it should be for a commercial product. Consequently, over 100 lb of hot water are used for dishwashing per day for an average four-member family. No known aerospace concept is being developed; however, there will be a requirement for a dishwasher in a space-station-type vehicle where disposable dishes and utensils are not contemplated.

Garbage and Trash Disposal. Garbage and trash disposal does not require a large quantity of water; however, this disposal problem is of interest since the solids may be processed in the same way as fecal solids. The Integrated Waste Management Program (AEC Contract AT[30-1]-4104) uses the approach of handling all the liquid and solid wastes by common processes; namely, distillation for water recovery and incineration for solids disposal. This approach in a household would initiate the separation of nonburnable trash, e.g., cans and bottles, which is difficult to separate after the trash leaves the home.

### Water Recovery

Space-type water recovery systems can be generally categorized as distillation type or filtration type, although some designs must use distillation and filtration to provide an acceptable product. Some systems also require pre- and post-chemical treatment. Chemical and sterility requirements from NASA for recycled water are much more stringent than those of the U.S. Public Health Service. Consequently, as public water supply standards become more stringent, the aerospace technology may be applied.

Distillation. The General Electric concept utilizes distillation and high-temperature catalytic oxidation with no pre- or post-treatment required. The product is pure and sterile. Distillation is achieved by use of waste heat, radioisotope heaters or vapor compression.

Several evaporator designs have been developed for operation in zero gravity; these use centrifuges, flash evaporators or membrane diffusers to achieve liquid/steam separation. The centrifuge design is also useful for solids separation. Air evaporation is another distillation technique which uses a heated airflow to evaporate water from a wick-type material. Both pre- and post-treatment are required.

Filtration. Filtration has been broadly defined to include processes such as electrodialysis, reverse osmosis and multifiltration. Reverse osmosis and multifiltration are most promising in that the process is simple and much development has been completed. For example, the Space Station Prototype will use a reverse osmosis unit for water recovery from wash water. Multifiltration was used in the NASA four-man, 90-day test to recover water for personal hygiene, laundry, and housecleaning. This unit used several particulate filters followed by an activated carbon column, two ion-exchange resin columns, and a final activated carbon column. The development of flocculants has permitted more efficient filtration.

Pre- and Post-treatment. There are a multitude of chemicals being developed for pre- and posttreatment for systems which cannot handle waste ammonia generation and/or do not sterilize the effluent. These range from electrolytic and dichromic acid pretreatments to chlorine and silver ion posttreatments. Usually, the pretreatment is used to complex the waste urea to prevent ammonia generation. The posttreatment is usually required to control microbial growth. A newly developed electrolytic-type chlorine generator eliminates the need of handling of gaseous chlorine.

### Solid Waste Processing

Basically, there are three advanced space vehicle methods for processing solids; namely, drying, such as is used in the General Electric Dry John commode, wet oxidation, and incineration.

Drying. Drying is accomplished by venting the closed waste container to vacuum, flowing an airflow through the container, or circulating and drying the airflow with a desiccant. Drying does not necessarily kill micro-organisms; however, the lack of water does prevent propagation and the resulting odors. Feces have been stored at ambie pressure, after drying, for in excess of 1 year wit out any gas generation problem.

Wet Oxidation. Among the several methods used for combustion of waste material is the Zimmerman or wet oxidation process. Waste material entrained in water, is placed in a pressure reaction chamber and air or oxygen is introduced under pressure to oxidize the organic content of the waste. The mixture is heated to 500-600° F in the closed chamber where a pressure of about 2000 psi is developed. Holding time depends upon temperature and composition of the waste, but about 1 hr is generally sufficient to oxidize 80 percent of the organic material and yield a sterile inoffensive end product.

Incineration. Incineration typically reduces solid waste volume and weight by 95 to 99 percent. The present General Electric incinerator for space applications uses a batch-type process. Continuous processes have been operated in the laboratory, but require more development to prevent clogging of the incinerator feed mechanism. Large-capacity, continuous-feed mechanisms are used in commercial incinerators.

### Ancillary Equipment

Aerospace development of water purity and sterility monitors is of special interest. Typically, pH and water conductivity are monitored and TOC, $NH_3$, Cl, and other ions can be detected. Bacteria sensors are of several types; namely, chemiluminescent, spectrographic, 4-hour incubation, chromatographic, and a real-time electromagnetic device that is in a very preliminary stage of development at General Electric.

## The Solution

### INTEGRATED SYSTEMS

With experience in the development of waste management systems for both space vehicles and homes, plus the experiences gained from research, development and marketing in the home appliance field, the various criteria which hardware must meet for either space or domestic applications can be compared knowledgeably. These criteria described in Table 1 are essentially the same for both applications, but differ in relative importance depending on the application.

A current contract sponsored jointly by the AEC and NASA is the Integrated Waste Management-Water System being developed at the General Electric Company. In this development, all wastes are collected in the evaporator where the water is distilled at a low temperature and the remaining solids are centrifugally removed from the evaporator (Figs. 6 and 7). The distilled water vapor contains impurities which are catalytically oxidized and vented to a space vacuum. The resulting ultrapure and sterile water vapor is condensed and the water is ready for reuse and consumption. The solid wastes are sterilized, dried, thermally decomposed, and incinerated with the resulting gases vented to a space vacuum. The small amount of remaining ash is sterile and may be stored or jettisoned. Methods of eliminating the vents to space have also been identified.

The high-temperature portion of the system is integrated and insulated to permit heating by one radioisotope heater or electrical heater. Radioisotope heating provides reliable high-temperature heating and significantly reduces the system's electrical power requirements.

### System Performance

System performance is briefly outlined as follows:

1. Collect and Process. Feces: 1.2 lb per day for four defecations. Urine: 14.0 lb per day from approximately 24 micturitions. Respiration and Perspiration: 20.0 lb per day at a continuous slow rate from the environmental control system. Wash Water: 24.0 lb per day. Trash: 1.2 lb per day — food, packets, wipes, and paper.

2. Water Recovery. Drinking Water: 30.0 lb per day. Wash Water: 24.0 lb per day.

3. High Temperature Thermal Energy. The system will have the capability of operation with a radioisotope heat source (RITE) or with an electrical heat source. Output: 400 Thermal Watts at End of Mission (Life). Fuel Form: Plutonium 238.

Integrated waste and water management systems can be derived for domestic use via the following concepts:

1. Concept 1. This system concept (Fig. 8) utilizes back contamination control devices to separate the community water supply from the system and to separate the waste collection devices from the washing and food preparation devices. In the home, back-contamination control is usually accomplished by an air gap between the potable water inlet and the water use device.

The waste liquid with a high-solids content, e.g., urinal, commode and garbage-trash disposal, is processed separately from the waste liquid with a low-solids content, e.g., wash water. This separation may be necessary to more efficiently process the wastes. For example, reverse osmosis may be used for water recovery in the wash water circuit and distillation for the commode circuit. Distillation will operate efficiently for the total water recovery process; however, the operational cost may be prohibitive since evaporation of each pound of water requires approximately 1200 Btu or 350 W-hr of energy. If the complexity is warranted, a vapor compressor can be added to the circuit to permit reuse of the heat initially used to evaporate the water, thus significantly reducing the overall energy requirement.

The solids from the waste liquid are separated and may be converted into either a sterile, dry material with little volume reduction or a sterile ash with a 95 to 99 percent volume reduction. The recovered water would either be drained to the sewage line or receive further processing to assure sterility and acceptability for watering the lawn or washing the family car. All excess water, over capacity inputs or potential overflows caused by component failure, will be bypassed to the sewage drain.

2. Concept 2. This concept (Fig. 9) contains all the elements of the first concept with a different arrangement. In concept 2, the wash water is processed to provide a sterile flush water for the urinals, commodes, and garbage/trash disposal. The resulting waste liquid is then processed to remove the solids and the resulting water is released to the sewage drain. The water is thus used twice before draining, and the reused water can be of a lower quality.

3. Concept 3. The third concept (Fig. 10) is a step closer to the NASA concept in that the water is recycled, and there is only a minimal reliance on the sewage drain during normal operation. The drinking and food preparation water is connected directly to the community water supply with no

connection to and, possibility of, back contamination from the remainder of the system. The wash water is recycled in the wash water circuit and the commode flush water is recycled to the commodes. There is no direct connection between the two circuits so that the possibility of contamination is minimized. Normally, only excess water is drained to the sewage line.

In 1872 London, Thomas Crapper was given Government grants to innovate and evolve waste management systems to solve the "shocking waste of water." So too, in 1971, NASA, 100 years later, has given grants via its aerospace technology programs in manned flight-waste management systems.

Future manned space vehicles will provide more earth like procedures for personal hygiene and waste management systems. Because the space vehicle is a smaller closed ecology than earth, space systems will provide more efficient and more microbiologically safe systems than are presently used on earth.

We cannot close our eyes to this technology. It is time to update Thomas Crapper's technology just as he updated the sanitary methods used over 100 years ago.

## Bibliography

1. Reyburn, W.: Flushed With Pride - The Story of Thomas Crapper. Prentice-Hall, 1971.
2. Small, W. E.: Agriculture: The Seeds of a Problem. Technology Review, April 1971.
3. A Study of Flow Reduction and Treatment of Waste Water from Households. FWQA Water Pollution Control Research Series, 11050FKE, 1969.

TABLE 1. TRADEOFF/SELECTION CRITERIA AND RATIONALE

| Criterion | Domestic | Space Vehicle |
|---|---|---|
| Feasibility | Must be feasible to manufacture on mass production basis. During development, compatibility with existing plumbing must be proven. | Must be feasible to make on a "cabinet work" basis. R&D must show proof of principle or reduction of practice but highly specialized materials and components can be used. |
| Cost | Must be competitive with products already on the market. Product improvement may occur over a period of years. | Cost important, but performance is overriding consideration. |
| Reliability | Motors usually guaranteed for one year, with 90-day guarantee on other components. Trouble-free operation is always the goal, but a service organization exists to take care of malfunctions. Operating environments are not severe and replacement is expected within a reasonable period. | Must be high. |
| Maintainability | Traded off against cost. Equipment designed for servicing by repairman rather than user. | Repairs must be made quickly and easily. (It should be noted that repairs will be performed by highly trained personnel.) |
| User Acceptability | Consumer acceptance in a mass market is key. Color, overall form and esthetic appeal extremely important. | Performance is key item. Esthetic appeal significant but secondary to function. |
| Safety | Underwriters Laboratories plus federal and state laws govern but failsafe devices usually not redundant. | Redundant failsafe devices required. |
| Performance | Nominal performance specifications since manufacturer has no control over operation and cost considerations may rule out improvements which consumers are unwilling to pay for. | Stringent performance specifications throughout the anticipated use life. Cost must be considered, but performance most important. |

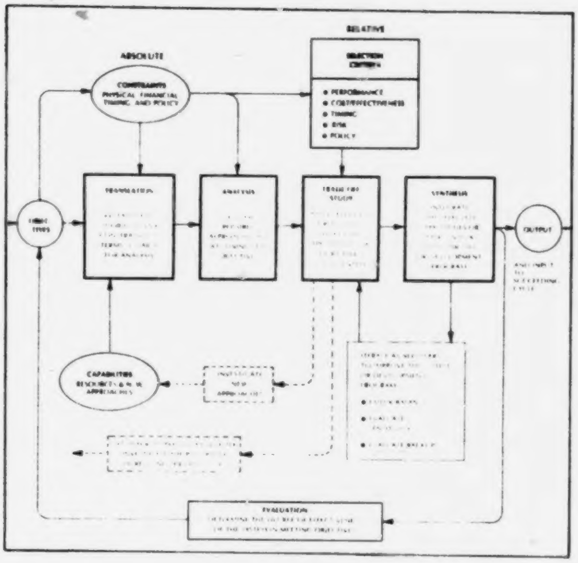

RELATIVE
ABSOLUTE
CONSTRAINTS
PHYSICAL, FINANCIAL, TIMING, AND POLICY
PERFORMANCE
COST/EFFECTIVENESS
TIMING
RISK
POLICY
OUTPUT
CAPABILITIES
RESOURCES & NEW APPROACHES
EVALUATION

Figure 1. Steps within systems approach.

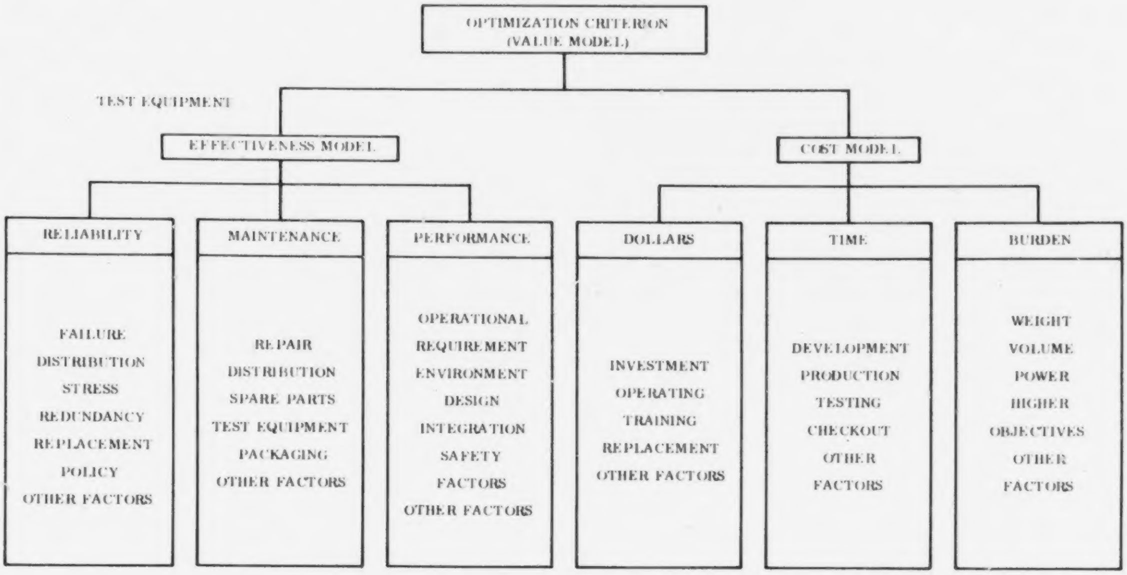
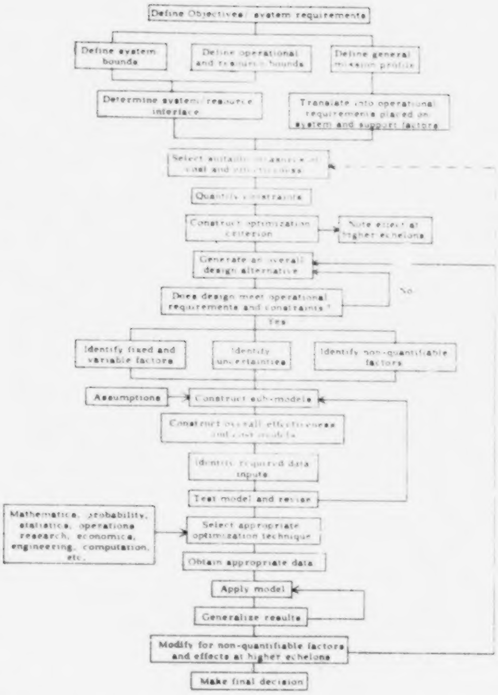

OPTIMIZATION CRITERION
(VALUE MODEL)
TEST EQUIPMENT
EFFECTIVENESS MODEL
COST MODEL
RELIABILITY
FAILURE
DISTRIBUTION
STRESS
REDUNDANCY
REPLACEMENT
POLICY
OTHER FACTORS
MAINTENANCE
REPAIR
DISTRIBUTION
SPARE PARTS
TEST EQUIPMENT
PACKAGING
OTHER FACTORS
PERFORMANCE
OPERATIONAL
REQUIREMENT
ENVIRONMENT
DESIGN
INTEGRATION
SAFETY
FACTORS
OTHER FACTORS
DOLLARS
INVESTMENT
OPERATING
TRAINING
REPLACEMENT
OTHER FACTORS
TIME
DEVELOPMENT
PRODUCTION
TESTING
CHECKOUT
OTHER
FACTORS
BURDEN
WEIGHT
VOLUME
POWER
HIGHER
OBJECTIVES
OTHER
FACTORS

Figure 2. Optimization criteria.


Define Objectives/ system requirements
Define system bounds
Define operational and resource bounds
Define general mission profile
Determine system/resource interface
Translate into operational requirements placed on system and support factors
Select suitable measures of cost and effectiveness
Quantify constraints
Construct optimization criterion
Note effect at higher echelons
Generate an overall design alternative
Does design meet operational requirements and constraints?
No
Yes
Identify fixed and variable factors
Identify uncertainties
Identify non-quantifiable factors
Assumptions
Construct sub-models
Construct overall effectiveness and cost models
Identify required data inputs
Test model and revise
Mathematics, probability, statistics, operations research, economics, engineering, computation, etc.
Select appropriate optimization technique
Obtain appropriate data
Apply model
Generalize results
Modify for non-quantifiable factors and effects at higher echelons
Make final decision

*EXTRACTED FROM AFSC-TR-65-4, VOLUME III

Figure 3. Optimization technique (flow diagram).

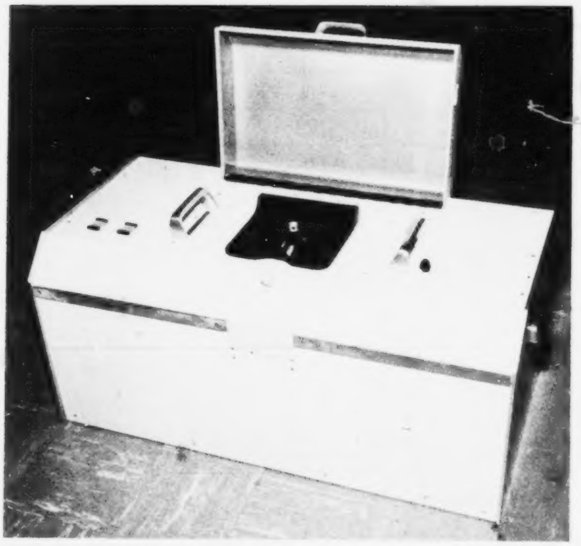


Figure 4. Modified Hydro-John separates solid waste from flush water.

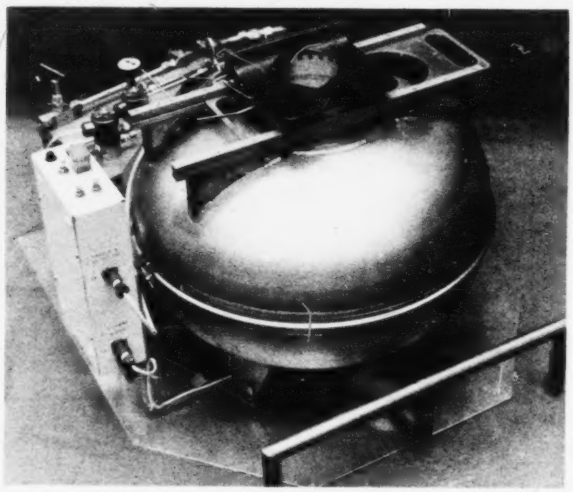


Figure 5. Dry John does not require flush water.

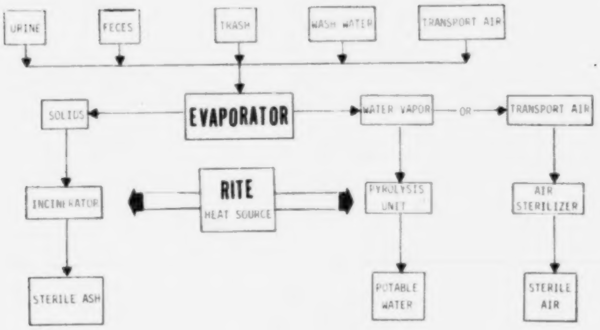

URINE
FECES
TRASH
WASH WATER
TRANSPORT AIR
SOLIDS
EVAPORATOR
WATER VAPOR
OR
TRANSPORT AIR
INCINERATOR
RITE
HEAT SOURCE
PYROLYSIS UNIT
AIR STERILIZER
STERILE ASH
POTABLE WATER
STERILE AIR

Figure 6. WM-WS functional diagram.

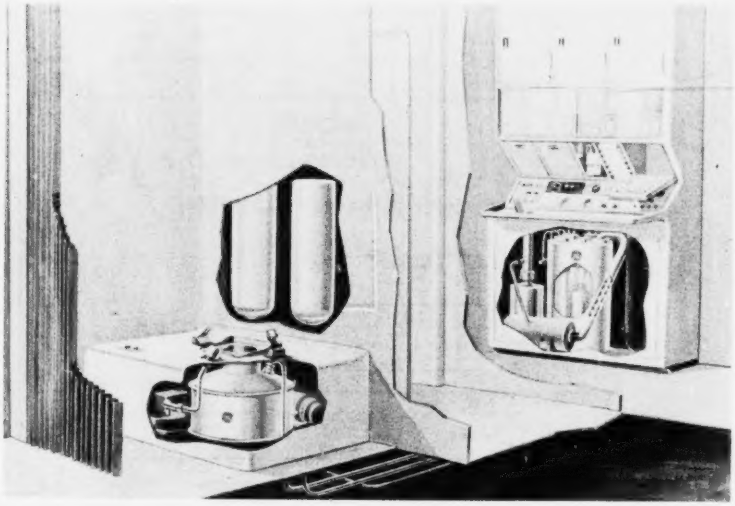


Figure 7. Artist's concept, integrated waste management-water system using radioisotopes.

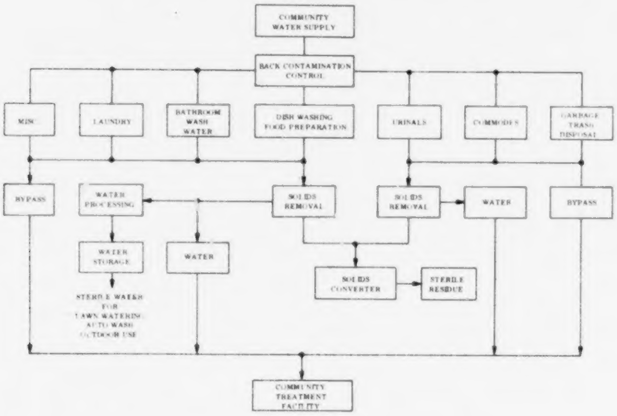

COMMUNITY WATER SUPPLY
BACK CONTAMINATION CONTROL
MISC
LAUNDRY
BATHROOM WASH WATER
DISH WASHING FOOD PREPARATION
URINALS
COMMODES
GARBAGE TRASH DISPOSAL
BYPASS
WATER PROCESSING
SOLIDS REMOVAL
SOLIDS REMOVAL
WATER
BYPASS
WATER STORAGE
WATER
SOLIDS CONVERTER
STERILE RESIDUE
STERILE WATER FOR LAWN WATERING AUTO WASH OUTDOOR USE
COMMUNITY TREATMENT FACILITY

Figure 8. Concept 1, integrated system.

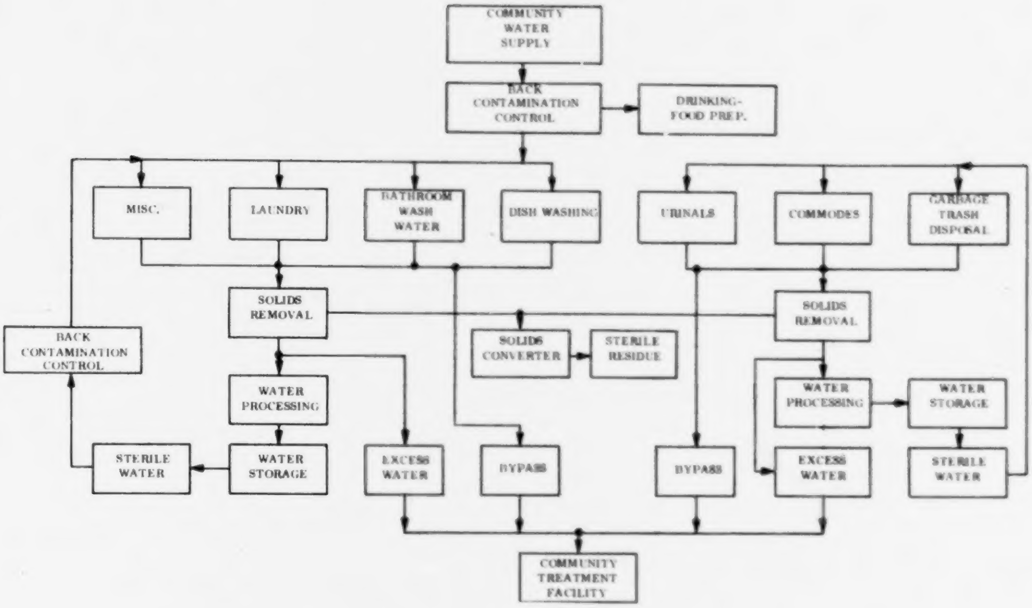

COMMUNITY WATER SUPPLY
BACK CONTAMINATION CONTROL
DRINKING-FOOD PREP.
MISC.
LAUNDRY
BATHROOM WASH WATER
DISH WASHING
URINALS
COMMODES
GARBAGE TRASH DISPOSAL
SOLIDS REMOVAL
SOLIDS REMOVAL
BACK CONTAMINATION CONTROL
SOLIDS CONVERTER
STERILE RESIDUE
WATER PROCESSING
WATER PROCESSING
WATER STORAGE
STERILE WATER
WATER STORAGE
EXCESS WATER
BYPASS
BYPASS
EXCESS WATER
STERILE WATER
COMMUNITY TREATMENT FACILITY

Figure 9. Concept 2, integrated system.

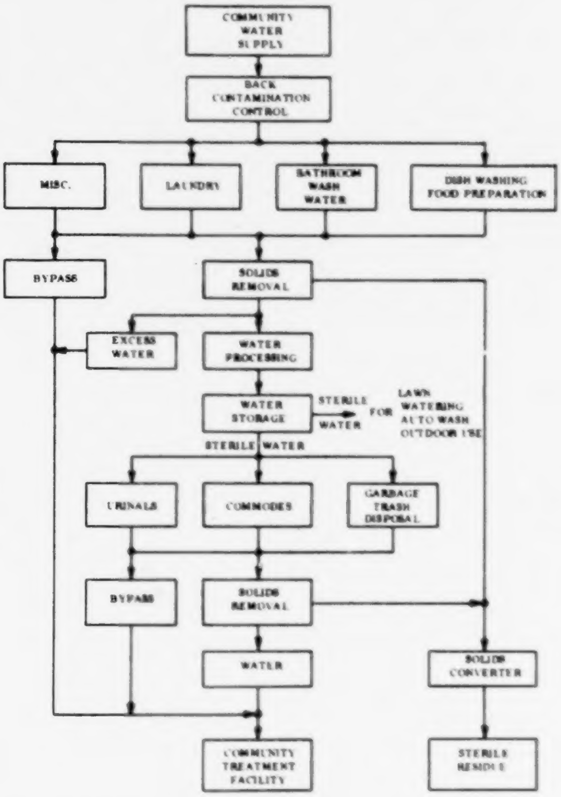

COMMUNITY WATER SUPPLY
BACK CONTAMINATION CONTROL
MISC.
LAUNDRY
BATHROOM WASH WATER
DISH WASHING FOOD PREPARATION
BYPASS
SOLIDS REMOVAL
EXCESS WATER
WATER PROCESSING
WATER STORAGE
STERILE WATER
FOR
LAWN WATERING AUTO WASH OUTDOOR USE
STERILE WATER
URINALS
COMMODES
GARBAGE TRASH DISPOSAL
BYPASS
SOLIDS REMOVAL
WATER
SOLIDS CONVERTER
COMMUNITY TREATMENT FACILITY
STERILE RESIDUE

Figure 10. Concept 3, integrated system.

# BREATHING METABOLIC SIMULATOR

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IBM Corporation

and

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## Introduction

The Breathing Metabolic Simulator (BMS) was developed by the IBM Corporation under the joint funding of NASA and the Office of Advanced Research and Technology (OART) and the Bureau of Mines. The BMS simulates man in the breathing and metabolic parameters required for evaluation and test of respiratory diagnostic, monitoring, support, and resuscitation equipment. For the first time, breathing and metabolic simulation are incorporated in a single device. Breathing rate, breathing depth, breath velocity contour, oxygen ($O_2$) uptake, and carbon dioxide ($CO_2$) release can be varied over wide ranges to simulate conditions from sleep to hard work, with respiratory exchange ratios ranging from hypoventilation to hyperventilation. Since the BMS can be remotely controlled in hostile environments, it can be used as a stand-in for humans in testing and validating respiratory equipment. In addition, it substantially reduces the cost of prolonged testing in cases where simulation chambers with human subjects would require three shifts of crews, including standby physicians. Perhaps, most important, it provides a calculated and reproducible test and validation facility.

The second-generation breathing metabolic simulator, currently under development, will be automated for computer control. Through a typewriter and paper tape the test sequence can be input into the computer which will then automatically adjust the BMS to simulate any desired sequence of metabolic activities for time durations up to 15 hours. The computer will also monitor the test procedures and provide printout of test results.

## BMS Design

Breathing Rate. The BMS contains a breathing rate adjustment that simulates human breathing rates, ranging from conditions of rest to hard work. However, this wide range would seldom be required in a single test.

Breathing Depth. The BMS breathing depth adjustment covers a range up to 3 liters per breath. Although an individual breath may exceed 3 liters under certain conditions, the breathing depth under continuous hard exercise should not exceed simulator capacity. Also, the BMS can simulate individual breath (tidal volume) which is normally 0.5-0.6 liter under rest conditions.

For special applications, the breathing depth can be expanded beyond 3 liters to simulate a full vital capacity, e.g., 6 liters.

Velocity-Time Waveform. A human breath velocity pattern is not generally represented by a true sine wave. It may vary from a slightly blunted sine wave to a drastic variation. To provide a true simulation, a waveform control is provided, allowing a wide range of variations from a basic sine wave.

Functional Residual Capacity (FRC). The FRC is the volume of air remaining in the lungs at the end of normal exhalation. To obtain an accurate simulation, the FRC must remain constant for breathing rate or depth changes. Also, the FRC must be variable to simulate individuals with different FRCs. Both of the conditions are provided by the BMS.

Exhaled Breath Temperature and Humidity. Exhaled breath, in humans, is at body temperature and, except for conditions of extremely hard breathing, at 100 percent relative humidity. Both of these conditions are simulated by the BMS.

Oxygen Consumption. The BMS provides a variable oxygen consumption rate to simulate the metabolic range between sleep and medium-hard work. For special applications, the BMS can simulate maximum oxygen consumption rates for the human undergoing maximum physical work.

Carbon Dioxide Production. The amount of $CO_2$ produced in the human is related to the amount of $O_2$ consumed. This $CO_2/O_2$ ratio is 0.707 if the fuel is fat and is 1.0 if the fuel is carbohydrates. This ratio, when referenced to tissue metabolic activity, is referred to as the respiratory quotient (RQ). When referenced to the ratio of gases in the exhaled breath (as in the BMS), it is referred to as the respiratory exchange ratio (R) (this differentiation is made because an individual may be underbreathing or overbreathing, markedly affecting the amount of $CO_2$ removed from the body and thus the value of R). To simulate these conditions, the BMS provides a range of $CO_2/O_2$ (R) wider than the normal range of 0.7 to 1.0.

## BMS Hardware

The BMS configuration consists of three subsystems:

1. Temperature/Humidity
2. Breathing
3. Metabolism

These subsystems are depicted in Figure 1.

### Temperature/Humidity Subsystem (Fig. 2).

Functions. Incoming air from the aritificial trachea is fed into an exchange box, where it is blocked from entering the humidity chamber by a check valve. The air then passes through another check valve and enters the main connection to the top of the bellows during bellows expansion.

Outgoing (exhaled) air comes from the main connection to the top of the bellows during bellows contraction. The air passes through a check valve and enters the input end of the humidity chamber. The air entering the chamber displaces air from the output end of the chamber through a check valve, where it enters the exchange box and exits to the artificial trachea.

Features. The check valves and exchange box are used to control airflow direction and to permit a single connection to the artificial trachea.

The humidity chamber is used to add moisture to the exhaled air and to maintain temperature within specified limits. The moisture transfer media (surgical sponges) remain saturated with water fro a separate reservoir (actual humidity is also affect by the dwell time of a breath inside the chamber). Temperature maintenance, accomplished by a heate blanket in the bottom of the chamber, is monitored by a thermistor placed in the path of the chamber output. Heater power is remotely controlled by the control unit.

This subsystem also contains sensors for monitoring the characteristics of the air to be exhal Wet and dry bulb thermistors placed in the output end of the chamber can be monitored by the digital voltmeter. A gas sample line, connected to the chamber input end, allows a sample pump to extract gas samples which are fed to the sensors of an $O_2$ analyzer and a $CO_2$ analyzer, and returned to the chamber. The readout of these analyzers is accomplished on the control unit.

### Breathing Subsystem (Fig. 3).

Functions. The breathing subsystem controls bellows expansion and contraction to draw air from and expel air to the temperature/humidity subsystem. The bellows motion is independently variable in rate, magnitude of periodic motion, and volume remaining at the point of minimum periodic volume change. The periodic motion of the bellows is accomplished by a drive motor operating a crankshaft/connecting rod combination through a 30:1 gear reduction. The drive motor speed is varied by means of a motor controller. Long-term variations, greater than one crankshaft revolution, correspond to changes in breathing rate and are varied from the control unit. Short-term variations, within one crankshaft revolution, correspond to changes in breath waveform and are varied by the individual settings of 12 waveform controls on the control unit. Each control is effective during one-twelfth of a crankshaft revolution as determined by a 12-position read switch.

Connecting rod motion is transmitted to the bellows by a lever arm operating on a movable fulcrum. Fulcrum motion along the lever arm varies the lever-arm ratio corresponding to changes in breath depth. This motion is accomplished by means of a lead screw from the fulcrum drive motor which, in turn, is controlled by the bidirectional fulcrum switch on the control unit. Fulcrum motion normal to the lever arm, i.e., moving the position of the bottom of the bellows for a fixed crank position and lever arm ratio, will change the minimum bellows volume obtainable through periodic motion. This corresponds to a functional residual capacity adjustment and is controlled by a manual screw adjustment on the support for the fulcrum base. This adjustment has a scale calibrated in FRC volume in liters.

Features. The top of the bellows contains two separate gas lines to provide an output to the compressor of the metabolism subsystem and to receive the output of this subsystem.

Two separate magnetic flux-type sensors are mounted between the bottom of the bellows and the adjustable support for the fulcrum base. These sensors measure position and velocity between mountings (thus sensing breath characteristics independent of FRC adjustment) and are input to the oscilloscope in the control unit, where either may be selected for waveform display.

### Metabolism Subsystem (Fig. 4).

Functions. This subsystem is used to control the simulated respiratory exchange ratio (R). Since R is a $CO_2$-to-$O_2$ ratio, metabolism is simulated by consuming $O_2$ and producing $CO_2$. This is accomplished by oxidizing propane and adding varying amounts of $CO_2$ in the following manner.

Air is drawn from the top of the bellows by a compressor. The compressed air output is then fed to an accumulator used to eliminate surging caused by bellows motion. The accumulator output is connected to an adjustable orifice used to preset the flow rate for more than sufficient air for all oxidation conditions; the accumulator is then connected to a gas line input to the oxidation chamber. A size-D tank of CP-grade propane is fitted with a manual regulator (set to 15 psi). The regulator output is connected to a solenoid shutoff valve controlled by the manual switch on the control unit (and the series safety circuitry discussed later). The solenoid valve output is connected to a remotely adjustable metering valve (controlled by the valve enable and $CO_2$ adjustment on the control unit). The metering valve output is connected to a flowmeter sensor (the flowmeter is located on the control unit panel) and finally to the oxidation chamber input line. A size-D $CO_2$ tank is fitted with a duplicate of the propane controls (except safety circuit not required) and also connected to the oxidation chamber input line.

The oxidation chamber is an expanded line area (made of quartz) containing a probe input for a chamber thermocouple and surrounded by an encased insulated heating element. Power to the heater is manually controlled (ON/OFF only) from the control panel combustion heater switch and maintains the chamber's temperature above that required for oxidation of propane. In operation, complete oxidation occurs with the chamber output having a $CO_2/O_2$ ratio which is variable, dependent upon the $CO_2$ and propane flow rates into the chamber (air input is a constant). The chamber output is fed to a radiant series cooler to reduce temperature to a safe level and then is returned to the top of the bellows.

Features. A safety circuit (Fig. 5) used to control propane flow will not allow the solenoid valve to be opened unless the proper oxidation conditions exist. The conditions monitored are the $O_2$ output level in the Temperature/Humidity subsystem, the compressor output pressure at the accumulator, and the chamber temperature.

The chamber thermocouple output can be monitored by the digital voltmeter to determine temperature during preheating or other conditions as desired.

The following expendables are required for operation:

| | |
|---|---|
| 1. $CO_2$ | Air Products size-D tank (4 in. by 17 in.) |
| 2. Propane (CP) | Air Products size-D tank (4 in. by 18 in.) |
| 3. Distilled water | Reservoir capacity (approximately 2.33 quart) |
| 4. Surgical sponge | Part-Davis gauze (approximately 4 in. by 8 in.) |

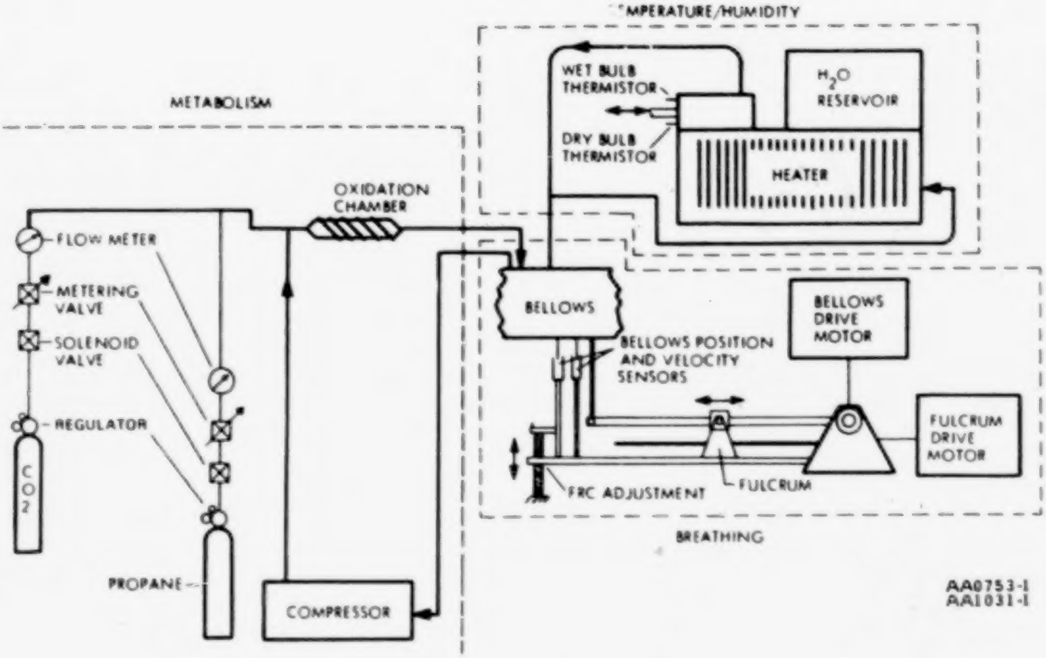
MPERATURE/HUMIDITY
METABOLISM
WET BULB THERMISTOR
DRY BULB THERMISTOR
$H_2O$ RESERVOIR
HEATER
OXIDATION CHAMBER
FLOW METER
METERING VALVE
SOLENOID VALVE
REGULATOR
CO2
PROPANE
COMPRESSOR
BELLOWS
BELLOWS POSITION AND VELOCITY SENSORS
BELLOWS DRIVE MOTOR
FULCRUM DRIVE MOTOR
FRC ADJUSTMENT
FULCRUM
BREATHING
AA0753-1
AA1031-1

Figure 1. BMS subsystems.

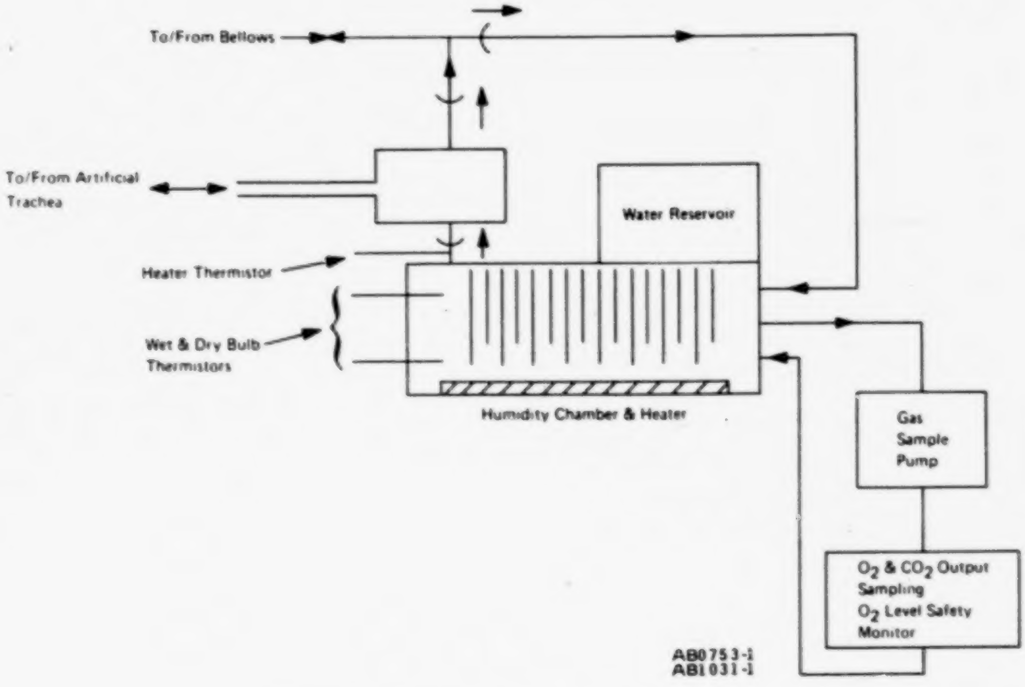
To/From Bellows
To/From Artificial Trachea
Water Reservoir
Heater Thermistor
Wet & Dry Bulb Thermistors
Humidity Chamber & Heater
Gas Sample Pump
$O_2$ & $CO_2$ Output Sampling
$O_2$ Level Safety Monitor
AB0753-1
AB1031-1

Figure 2. Temperature/Humidity subsystem.

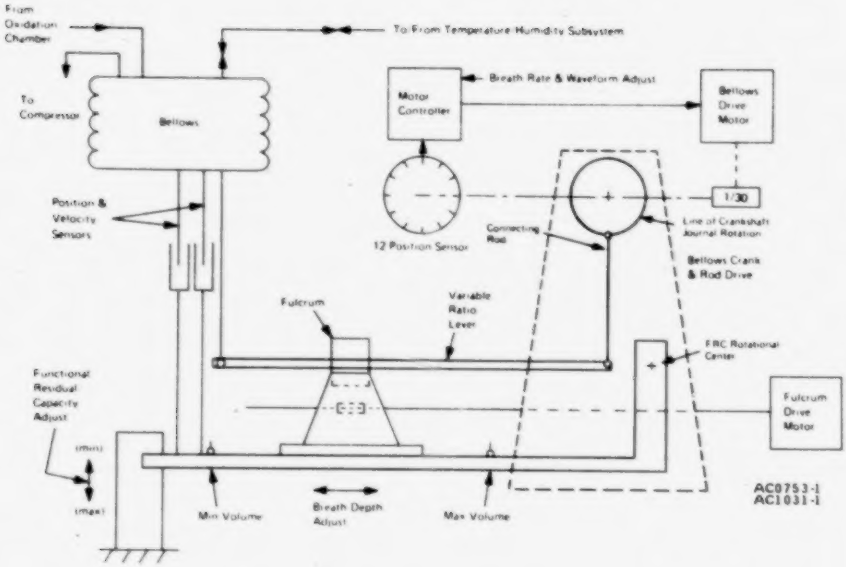
From Oxidation Chamber
To/From Temperature/Humidity Subsystem
To Compressor
Bellows
Motor Controller
Breath Rate & Waveform Adjust
Bellows Drive Motor
Position & Velocity Sensors
12 Position Sensor
1/30
Connecting Rod
Line of Crankshaft Journal Rotation
Bellows Crank & Rod Drive
Fulcrum
Variable Ratio Lever
FRC Rotational Center
Functional Residual Capacity Adjust
(min)
(max)
Fulcrum Drive Motor
Min Volume
Breath Depth Adjust
Max Volume
AC0753-1
AC1031-1

Figure 3. Breathing subsystems.

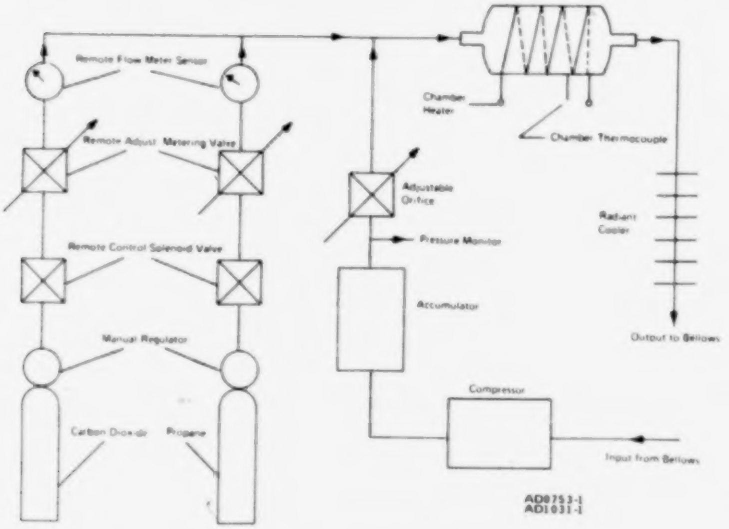
Remote Flow Meter Sensor
Remote Adjust Metering Valve
Remote Control Solenoid Valve
Manual Regulator
Carbon Dioxide
Propane
Chamber Heater
Chamber Thermocouple
Adjustable Orifice
Pressure Monitor
Accumulator
Radiant Cooler
Output to Bellows
Compressor
Input from Bellows
AD0753-1
AD1031-1

Figure 4. Metabolism subsystem.

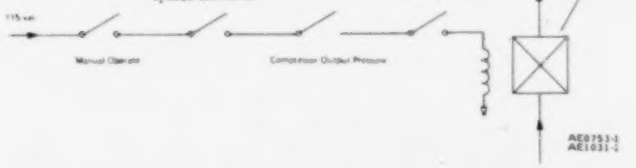
115 vac
$O_2$ Output Level Monitor
Oxidation Chamber Temperature
Remote Control Propane Solenoid Valve
Manual Operate
Compressor Output Pressure
AE0753-1
AE1031-1

Figure 5. Metabolism subsystem's safety circuit.

# MEDICAL TECHNOLOGY ADVANCES FROM SPACE RESEARCH

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Houston, Texas

## Abstract

A number of medically oriented research and hardware development programs have been sponsored by NASA for support of manned space flights. Some of these medical programs for manned flights resulted in the development of technology which advanced the state of the art and, when applied to earthbound medical tasks, truly represent medical benefits from space research. These advances include computer techniques to remove irrelevant details from medical X-rays, sight-operated switches to assist patients who cannot move their extremities, wireless cardiac monitoring for intensive care units, and many others.

Currently there are several NASA-sponsored medical research and development programs which have significant potential for ground use as well as space application. The integrated medical laboratory, now under development by NASA, incorporates many advanced features, such as digital biotelemetry systems, automatic visual field mapping equipment, sponge electrode caps for clinical electroencephalograms, and advanced respiratory analysis equipment. A preliminary flight design has been completed and a functional testbed unit is contemplated for the mid-seventies. Modules of this integrated medical laboratory may be useful in ground-based remote area and regional health care facilities as well as on long-duration space missions.

## Introduction

The National Aeronautics and Space Administration has had a number of medical development programs in support of space flights. Some of these medical development programs have produced technology which has been applied to ground-based medical use.

These space-oriented medical programs were started prior to the Mercury flights and have continued to the present time.

## Background

The Mercury program started with Alan Shepard's 15-min suborbital flight and ended with Gordon Cooper's 34-hour 20-min flight.

The Gemini program paved the way for man's first flight to the moon. The first Gemini flight was March 1965 and the last was November 1966. The first manned Apollo flight was in September 1968. The first manned landing on the moon by Neil Armstrong and Buzz Aldrin was in July 1969. Perhaps in the distant future, interplanetary flights lasting as long as 2 years or more will be flown. Skylab is scheduled to be the first of the long-duration flights. Three men will live in an orbital workshop for periods lasting as long as 56 days.

The Shuttle and Space Station complexes are currently planned for the late seventies and early eighties, and the Space Base during the eighties. Beyond space bases there may be manned planetary missions.

The early NASA biomedical systems were used in two ways: to monitor vital physiological parameters such as heart rate, blood pressure, respiratory rate, electroencephalogram, and body temperature; and to conduct medical experiments to answer specific scientific questions. The vital physiologic functions were mentioned on all of the manned space flights.

Changes in the cardiovascular system were studied on the Gemini VII mission, which was the longest of the Gemini flights. Gemini VII indicated it was possible to fly an Apollo mission to the moon without expecting any serious physiological degradation in the crewmen.

The biomedical systems used during Mercury, Gemini, and Apollo answered many questions. The ability of man to exist safely in space flight for 14 days was proved. Man can probably live and work safely during extended-duration missions lasting 30 days.

Physiological studies, such as lower body negative pressure experiments, were performed before and after missions. Extensive pre- and post-flight testing was accomplished for all NASA manned space flights.

Bioinstrumentation used in space flights was developed to meet the rigorous requirements of size, weight, and power consumption of the spacecraft. In some cases, complete new bioinstrumentation systems were necessary to accomplish a specific physiological study. Inflight recorders, blood pressure apparatus, and biopotential signal conditions were assembled as prototypes and subjected to tests that lead to flight qualification.

Physiological data were telemetered to ground stations or recorded for playback. Physiological data were recorded in flight with the crewman at rest, as well as during exercise periods, for blood pressure, electrocardiogram, and respiration parameters.

The Skylab program should provide the medical scientist with the necessary data to assess the effect of the spaceflight environment on several of man's physiological systems for periods of time lasting as long as 56 days. The Skylab orbital workshop will be launched unmanned into earth orbit. Three crewmen who will inhabit the workshop for periods of time as long as 28 days will be launched in an Apollo Command and Service Module. Two subsequent three-man crews are scheduled to inhabit the Skylab workshop for periods as long as 56 days. Medical equipment to be flown on these flights will permit the measurement of physiological parameters.

Major areas of medical study in the Skylab program include the cardiovascular responses to exposure of the crewmen to lower body negative pressure; respiratory, cardivascular, and metabolic responses to a programmed workload on the bicycle ergometer; and vestibular responses to rotation and attitude changes in a rotating litter chair [1].

Exposure of the crewman's legs and lower torso to reduced atmospheric pressure, in some respects, duplicates the pooling of blood in the lower extremities while standing in 1 g. This passive cardiovascular stress will allow the medical scientist to determine, to some extent, the effects of the 0-g environment on the crewman's cardiovascular status. Repeated regular lower body negative pressure (LBNP) exposure may serve, as a countermeasure, to keep the cardiovascular system in good condition for return to 1 g.

A bicycle with a programmable workload was developed for Skylab. The ergometer workload is automatically adjusted to maintain a preset heart rate. During the time the crewman is on the bicycle his physiological responses are recorded onboard the workshop and may be transmitted to the ground in real time or at a later time for analysis. In addition to providing valuable physiological data, the bicycle ergometer will also function as a 0-g deconditioning countermeasure.

The Skylab rotating litter chair will impart small gravitational forces to the vestibular canals in the inner ear. The vestibular apparatus in man is normally subjected to 1 g and helps man to determine his position relative to the earth, but in 0 g it may be more sensitive to gravitational disturbances.

The central nervous system's functions will be monitored during sleep by the Skylab sleep cap, electroencephalogram signal conditioner, and the Frost sleep analyzer.

The Inflight Medical Support System (IMSS) is to provide, in the Skylab workshop, a limited inflight medical diagnostic and treatment capability for routine and emergency medical care of an outpatient nature [1]. The IMSS consists of two basic groups of equipment, diagnostic and therapeutic. For diagnostic purposes, the IMSS is supplied with the standard clinical instruments such as stethoscopes, sphygmomanometers, thermometers, etc. Additionally, medical laboratory equipment is provided that will allow blood analysis, urinalysis, and microbiological examinations. For therapeutic purposes, the IMSS is supplied with a wide selection of drugs. It is also outfitted with a minor surgery pack for the care of minor lacerations.

Perhaps in the distant future, interplanetary flights will last as long as 2 or more years. How will man's physiological systems adapt to prolonged periods of weightlessness of 1 yr or more? Will man's behavior change; and if so, how will the changes affect his performance? Are there any countermeasures which might be employed to prevent, correct, or delay deconditioning?

The Skylab missions should serve much the same scientific purposes for these extended missions as the Gemini VII flight served for the Apollo program. However, the bioinstrumentation systems and medical experiments on Skylab will not be adequate to answer all of the significant physiological questions about extended-duration missions. Thus, the Skylab medical experiments may only raise additional questions.

The extended-duration missions will require more comprehensive capabilities in the areas of medical research and clinical medicine. Onboard laboratory facilities will be required to measure such diverse factors as lung volumes, lung diffusion capacity, urine and blood ion content, red blood cell fragility, and sensory perception.

As crew size increases from 3 men, on the Skylab missions, to 12 men, as proposed for early space stations, the onboard clinical medicine support for the crew must be expanded. The Skylab IMSS will be adequate to provide support for 3 men in space for up to 56 days, but not for 12 men for 1 yr or more.

As a result of these considerations, NASA is developing the Integrated Medical and Behavioral Laboratory Measurement System (IMBLMS).

The IMBLMS will provide for onboard medical support of the crew and medical research. The medical support system will provide the capability for diagnosis and treatment of illnesses and injuries. The medical research system will provide a core laboratory that will allow the life scientists to conduct a comprehensive series of physiological and clinical measurements in flight. Data for display, storage, playback, and transmission to the ground will be processed by IMBLMS.

Flexibility in the IMBLMS design will permit changes in capability and equipment integration from mission to mission. Each major IMBLMS component must be capable of being used individually or in combination to perform many different measurements. By the use of a flexible design approach, IMBLMS will not only be suitable for use in early extended space flights, but will also have the potential to accommodate new measurements developed in the future to meet the changing mission requirements.

In 1968, NASA elected to design, build, and test functional breadboards of the IMBLMS to demonstrate flight-applicable techniques and gain information needed to develop requirements for flight hardware and software. At this stage of development it was premature to include any flight packaging. The information collected during the production and testing of the functional breadboards was applied to the preliminary flight design which followed.

The functional breadboard systems (FBBs) were delivered to the Manned Spacecraft Center (MSC) in January 1970, and were installed and operational in February 1970. Since that time the FBBs have undergone extensive testing and analysis. The testing was intended to establish the value of the techniques under study; however, this testing also demonstrated that some of the techniques were inadequate, too complex or time consuming to be included in the flight designs [2]. Alternative techniques are being sought for those measurements considered essential to the flight system, but were obviously inadequate techniques in the breadboards.

The Integrated Medical and Behavioral Laboratory Measurement System is an advanced medical system which may have applications on earth as well as in space.

## Benefits

With this brief overview of NASA's medical development programs, it is easier to grasp the potential for future medical technology applications from space research as well as understand those which have already occurred. A partial listing of NASA's technology, which has been applied to ground-based medical use, includes infant breathing monitor, X-ray enhancement, pressure transducer for cardiac catheters, special biopotential electrodes, and an artificial heart controller [3].

Infants, comatose children, or adult patients sometimes require surgical implantation of a tracheotomy tube in the windpipe. If the tube is clogged, cutting off breathing, brain damage or death can result within from 2 to 4 min. Ordinarily a full-time nurse is required to visually check the tube and take immediate corrective action. Integrated circuitry, designed and fabricated for aerospace use, was incorporated in a small device to monitor the temperature of air passing through the tube and actuate an audible or visual alarm within 10 sec of any change. The signal can be given at a nurse's station, or in another room, if the patient is at home. Thus the patient's care is improved and facilitated.

The breathing monitor, based on an automatic air surveillance system developed by NASA scientists, contains a temperature sensor/FM transmitter attached directly to the tracheotomy tube to allow the inspired and expired air to flow directly over a thermistor temperature sensor.

Techniques for the correction of photometric, geometric, and frequency response distortions in television pictures received from a spacecraft have now been applied to the study of medical X-rays. The X-ray picture is first converted into digital form by means of a cathode-ray device that scans the film on a line-by-line basis and converts each point of the picture into a number proportional to the film's optical density. Each sample (typically 500 000 samples for a 1-in.$^2$ transparency) is recorded on a magnetic tape which is subsequently fed into a computer.

Further computer enhancement is achieved by a two-dimensional digital filter to modify the frequency spectrum of the picture. Filtering is used to restore high-frequency losses of fine detail resulting from the use of fluorescent X-ray intensifying screens.

Another computer processing method involves image subtraction. Two pictures depicting the same area of the body, perhaps taken at different times, are subtracted from one another on a point-by-point basis. The resultant difference picture will emphasize changes, such as tumor growth.

The operational principles of a sensitive micrometeorite detector have been used to develop a muscle accelerometer. Change in acceleration of this instrument causes the deflection of a sensitive piezoelectric crystal. The accelerometer is attached to the patient to provide an accurate record of very slight muscle reflexes and tremors.

Use of the instrument is proving valuable in current studies of reflexes and tremors associated with neurological disorders. Previous studies based on motion pictures and direct visual observation were unsatisfactory in obtaining accurate quantitative data. For example, accurate determination of the time cycle of arm movements previously required tedious examination of many motion pictur frames, while low-amplitude tremors remained undetected.

An astronaut's space helmet provided a development model for research on oxygen consumption of children at a university medical center. The children, both normal individuals and those with heart defects, experienced difficulties and discomfort with the conventional rubber mouthpiece used for collection of exhaled breath. During heavy breathing, the comparatively high resistance to the flow of gas increased the workload on the subject. The extra effort required additional oxygen which impaired the accuracy of the data on oxygen consumption.

A solution was offered by a modified NASA space helmet which was equipped with an air inlet and outlet and a rubber seal around the neck. A suction pump was provided to continuously circulate fresh air through the helmet, picking up the exhaled breath and drawing the combined fresh air and exhaled breath into an oxygen analyzer.

When a pediatric cardiologist experienced difficulties in obtaining accurate electrocardiograms from children during exercise, he adopted a technique for conducting medical research on test pilots. The use of an electrode sprayed onto the body of an astronaut had improved the accuracy of electrocardiograms by reducing variations in the electrical contacts produced by movements of standard metal-plate electrodes.

A modified commercial spray gun is used to spray an electrically conductive mixture of a commercial household cement, silver powder, and acetone, as well as air-drying the deposit at an air pressure of about 20 psi. The mixture is simultaneously sprayed over the end of the lead wire from the electrocardiogram and a half-dollar area of skin, previously cleaned and coated with an electrode jelly. The application of the electrodes does not require removal of hair, and the thin, flexible layer is quickly removed with acetone.

Transducers originally designed for pressure survey probes in wind tunnels and for telemetry of pressure data from small free-flight models have been adapted for measurement of intravascular pressures in humans. A miniature diaphragm-type capacitance transducer was designed to be fitted on the end of a cardiac catheter and inserted by percutaneous techniques, using standard needles that are routinely used for venous or arterial punctures.

The two capacitor plates, used to sense pressure, consist of a cell diaphragm and a film of platinum fired onto a glass core separated by an air gap. The central metal tube in the cell provides an electrical connection to the platinum film and serves for passage of reference pressure to the capacitor air space. The electronic system, connected to the catheter for sensing pressure, consists of a capacitance bridge network excited by a crystal oscillator, a low noise transistor amplifier, and a demodulator for producing an analog signal or a CRT display.

A major problem in teaching a handicapped person to walk is to help him make an easy transition to his old environment. There are many severely handicapped persons who, after a prolonged immobile period in bed, experience great difficulty in adjusting to walking with crutches or sitting up in a wheelchair. In addition, there is the problem of a patient learning to walk with artificial legs under normal weight/gravity conditions. A definite need was found for a partial support system to reduce the physical workload imposed on such a patient during this training and transition period. Water-bath support systems being used were inconvenient and hampered limb motion. A lunar-gravity simulator was found adaptable to this problem. The device can be adjusted for any degree of support required, and the sling is more comfortable than a harness.

One of the concerns in using radiation therapy for cancer is preventing damage to the surrounding healthy tissue. Radiation therapists needed to measure the radiation level absorbed around the cancerous area in order to either control the treatment with improved precision, or to determine the position of administered radioisotopes rapidly and accurately. A miniature radiation-dosimeter probe was made available for such use. The probe, approximately the size of a clinical thermometer, is based on solid-state and semiconductor phenomena.

A list of representative medical technology, which is developed but not generally applied, includes such items as dry stained slides. These prestained slides employ a specific mixture of dyes which have been predeposited as a thin, dry film on the surface of a standard microscope slide. A hinged coverslip, in conjunction with the label, is also attached to make a complete slide assembly so that the following routine blood tests can be conveniently performed on a single slide: platelet estimation, reticulocyte count, and white blood cell differential count. This technique reverses the procedure normally practiced with traditional bloodstains. The blood sample is deposited first with these, followed by the application of the stain. Elimination of the necessity for manipulating basic/volatile stains by the technician, with concomitant increase in time, allows preparation of the blood smear in essentially one easy operation. The prestained slide technique also permits the performance of these clinical tests on blood uncontaminated with heparin or other anticoagulants, which may have an effect on cellular morphology.

Slight differences in staining characteristics will be noted as the result of the new dye mixture employed. These differences are easily overcome with minimal observation of the preparations through the microscope; experience has shown that personnel familiar with the Wright's stain technique are able to adjust to the prestained slide characteristics with only 10 or 15 min of practice.

The National Institutes of Health and National Institute of Cancer are now evaluating these dry stained slides with pathological blood samples for possible application in cancer research.

The automatic blood pressure measurement system developed for Skylab has several unique features which permit an accurate measurement of blood pressure even during exercise.

Dry silver chloride electrodes were developed for manned testing, which have small impedance balancing amplifiers embedded in the electrode.

A three-dimensional tremor and reaction detector has been developed and is now being tested with normal subjects, as well as with patients who have neurological disorders.

The mass spectrometer developed for the Skylab metabolic analyzer is being configured to measure oxygen consumption and carbon dioxide production by patients in intensive care units as well as to measure blood gas concentration in near real time.

The Frost analyzer, which is to be used on Skylab as a sleep monitor, may be applicable to operating rooms to monitor the level of anesthesia.

Initial studies of this application of the sleep monitor are now underway in the Texas Medical Center.

There are many items of medical hardware, which have been breadboarded for ground-based study, that were designed but not fabricated for use in space. A few representative items of this type of development hardware include an automatic peripheral visual-field mapping system. Normally visual fields are mapped in a manual mode which is time consuming and often not as accurate as might be desired. The NASA system operates much like an automatic hearing tester (if you hear a sound, push the button until the sound goes away), only for the vision system the test involves light instead of sound.

A disposable sponge electrode cap in the international electrode configuration for the electroencephalogram was developed and tested on a limited basis. The clinical electroencephalograph cap seems to have considerable potential for ground-based use.

A digital biobelt is being developed which has several advantages over present body-worn systems. All components will be microminiaturized. Digital data may be brought off the man by use of very small coaxial cables or via an RF link. The biobelt incorporates optical couplers and advanced current-limiting devices for improved safety.

There are a number of medical research and development programs in the feasibility stage that have considerable potential for space and ground-based applications. The Microbial Ecological Monitoring System (MEMS) is a passive immune agglutination test for rapid viral identification. Small Latex beads, 2.0 to 0.2 mg in size, are coated with specific antibodies which have been developed in animals exposed to the viruses. These antibody-coated beads clump or agglutinate when exposed to the specific virus antigen to which they are sensitive. The organisms which have been tested to date are myxovirus, adenovirus, herpesvirus, echovirus, coxsackie virus, and mycoplasma. The advantages for space application are the same as on the ground and include rapid screening (a few minutes versus the 2 weeks at the present). The test is highly specific, may be accomplished by a technician, and should cost less than the present tissue-culture techniques.

The objective of the three-dimensional vector cardiograph presentation is to test and verify a new semiautomatic, three-dimensional display of a vectorcardiogram in a clinical setting. The system is designed as a display capable of presenting a vectorcardiogram (VCG) in three-dimensional perspective. The system is based on the Data General NOVA machine; data are displayed on an oscilloscope and on an X-Y plotter. Projections of the individual VCG complexes on the standard anatomical axes or on rotated axes are provided. Horizontal, frontal, and sagittal plane displays are available for comparison with the three-dimensional VCG display.

This system, if successful, will provide a powerful tool for interpretation of VCGs and must be tested in a clinical setting with both normal and abnormal data to verify its function and capabilities. The method of presentation should be valuable to spaceflight research and ground-based medicine.

Initial studies conducted by MSC using stereophotogrammetry for determining body shapes in three dimensions have shown a high probability of developing into a highly accurate, space-compatible technique for measuring body volume.

The fact that organic structures are inherently three dimensional opens up a wide range of possibilities from microscopic studies to investigations of whole body form. A varied research embracing such areas as spinal deformities, prosthetic design, body and limb plethysmography, tumor detection and growth is being conducted at the Texas Institute for Rehabilitation and Research, Baylor College of Medicine, MSC, and other institutions. The need for an accurate and practicable means of measuring body surface areas, volumes, volume distribution curves, deformities, changes in form, and related parameters of intact organisms or their parts would seem to assure a bright future for stereometrics in the biomedical sciences and clinical practice.

A miniature analytical laboratory system designed to operate on spaceships for monitoring the health of astronauts is being developed at Oak Ridge National Laboratory. The minisystem is called the gravity-zero analyzer (G0 analyzer) because it will be designed to operate in the weightlessness of outer space. The G0 analyzer will utilize the technology developed under Oak Ridge National Laboratory's basic, fast analyzer work at the laboratory's Molecular Anatomy program.

The G0 analyzer will be designed to permit astronauts to perform, quickly and automatically, up to 16 parallel chemical tests on 0.1 ml of plasma or serum based on calorimetric determinations. Results of the test will automatically be radioed to ground control. One application of the system would be to analyze the blood and urine of an astronaut if he were to become severely ill during spaceflight. The system will consist of an enclosed rotor, drive mechanism, and stationary calorimeter for automatically dispensing the sample, mixing it with the necessary reagents, and measuring the optical density of each of the reaction mixtures during rotation. The G0 analyzer system will be useful in hospital emergency rooms and pediatricians' offices because it requires very little space, small samples, and is simple to operate.

In addition to its principal application on long-duration space missions, IMBLMS may have applications on earth. The IMBLMS program, established to provide systems capability for conducting biomedical experiments and clinical support, might offer some relief of the medical care problems that exist in the U.S. today.

There is widespread dissatisfaction with the delivery of health services in this country. The Department of Health, Education, and Welfare's report, "Report on the Health of the Nation's Health System," released in 1969, suggested that the U.S. faces a massive crisis in health care delivery. The problems of the health care system include: (1) inaccessibility of health services for many Americans, especially those who live in remote rural areas or in the inner city; (2) the U.S. health care establishment consists of government, industrial, and private interests who suffer from a lack of adequate means for communication and inadequate organization which adversely affects the availability, quality, efficiency, and cost of health services; (3) the cost of health services continues to rise above the financial capabilities of a large number of citizens; and (4) health personnel are in short supply, maldistributed, and specialized without regard to needs.

While the application of IMBLMS technology could obviously not cure all the ills of the U.S. health care establishment, it could be adapted for use on earth as a health services access system with the following features: (1) the use of an integrated medical, communications, and data management facility manned by physicians' assistants to provide points of entry into the health care establishment for people in medically deprived areas; (2) the provision for outpatient services on a local level coupled with the use of communications technology to provide the consultation support and supervision of the physician's assistant; (3) the adequate disposition of medical and traumatic emergencies; (4) the use of appropriate combinations of fixed and mobile facilities to meet the varying needs dictated by population density, terrain, existing transportation systems, and socioeconomic characteristics of different areas; and (5) the use of information processing to relieve personnel of burdensome recordkeeping and administrative functions. These features permit efficient use of the physician's time and are essential for support and supervision of the physician's assistants.

Conceptually, a national network of health services units could be developed, although initially, a demonstration program would be a cost-effective method to establish the feasibility of the basic approach. The exact configuration of the demonstration program units would depend on the site or sites selected, but basically the system may be described as follows.

The remotely located field units would be supported by a control center located adjacent to a large hospital emergency facility. The control center would be in constant communication with the remotely located elements of the system. The local center would be a fixed facility located in a town without a medical clinic or hospital. The local center would offer outpatient and emergency health services and would serve as a relay point for communications with other more remotely located facilities. The mobile facility would be a scaled-down version of the local center which would be capable of offering health services to fewer people but has the advantage of being transportable over major roads, on a scheduled basis. The ambulances and hand-carried equipment would further extend the system to difficult-to-access areas.

The IMBLMS could be adapted very profitably for use on earth as a health services unit. Moreover, the IMBLMS program could offer other benefits to the general public, such as newly defined measurements, techniques, equipment, and ultimately, important tools for extending medical services.

## Conclusion

Many medical research and development programs have been sponsored by NASA for space application. These efforts to develop techniques and equipment for application in space have resulted in medical benefits to the general public. Some medical programs for manned flights resulted in the development of technology which advanced the state of the art and, when applied to earthbound medical tasks, truly represent medical benefits from space research.

Currently there are several NASA-sponsored medical research and development programs which have significant potential for ground use as well as space application. The integrated medical laboratory now under development by NASA incorporates many advanced features, such as digital biotelemetry systems, automatic visual field mapping equipment, sponge electrode caps for clinical electroencephalograms, and advanced respiratory analysis equipment. A preliminary flight design has been completed and a functional test bed unit is contemplated for the mid-seventies. Modules of this integrated medical laboratory may be useful in ground-based remote area and regional health care facilities as well as on long-duration space missions.

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# SESSION V
# BENEFITS TO TELECOMMUNICATIONS, NAVIGATION, AND INFORMATION SYSTEMS

# SATELLITE COMMUNICATION AND NAVIGATION FOR MOBILE USERS

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When people think in terms of satellite communication they probably think of a very large fixed-earth station. But there is another class of user, typified in Figure 1. It is the individual highly mobile user, in this case, an Air Force KC-135. As opposed to the fixed-earth station, he might have only very low-rate teletype communications to be broadcast back to some central facility, or air-to-air communications.

Obviously, it is rather impractical to put a 60-ft dish antenna on an aircraft. Instead, as can be seen on the figure, a very small blade antenna is ordinarily used for aircraft communication. This breakthrough in satellite communications has been made possible by advances in the last 6 years or so. Most of the applications that have been looked at have been for the military, although NASA performed some communication experiments with ground stations and commercial airliners with their Applications Technology Satellite (ATS-I).

A large number of uses for satellite communications to mobile users in the civilian section is seen in Figure 2. A problem, for instance, exists with transoceanic airline communications. When a commercial airliner is on a long-distance flight from this country to Europe, or especially over the Pacific, it has to rely on what is called high-frequency (HF) communications, which, although it provides considerable range, is somewhat dependent on the sunspot cycle, the weather, the day of the week, the hour, etc.; and communications are not highly reliable. A satellite always hovering overhead, however, would provide a reliable link. The same fact holds for ships; they too have to rely on HF for their long-range communications, and the satellite would be benefiting them also. All types of emergency communications in inaccessible regions, such as jungles, or any sort of disaster area where communications are needed in a hurry, can be set up quickly with the types of satellites I will discuss in the following. As I mentioned before, the military has been the most interested party in satellite communications for mobile users.

Satellite communications for mobile users have a number of characteristics in the type of communication that are different from the types that the Commercial Satellite (COMSAT) has to deal with or the type of communication that NASA requires, getting information back and forth from astronauts in orbit or around the moon. Figure 3 shows a number of characteristics that would be typical of the mobile user. First of all, there would be a large number of intermittent users. We are not talking about a user who is on the air all the time; he is someone who will want to "push-to-talk," as they say. He just wants to get a quick message over and back. Of course, the satellite ground stations themselves are very numerous. We are not just talking about a few large stations that can cooperate with each other in terms of sharing the power of the satellite or its bandwidth; thus, we are dealing with a large number of intermittent users, and the equipment that these users are going to have must be easy to use and inexpensive. The operators of this equipment will not be trained satellite communicators; more typically, they will be radio operators. The communication facilities should be as easy to use as a radio set now; and obviously, the cost is going to have to be kept down. The operating frequency directly determines the type of antenna that can be used on these terminals. On the aircraft, I indicated the blade antenna, as it is called. It is most appropriate in the UHF, the frequency band just below the microwave frequencies for satellite communication, which are also typical of current air-to-ground communications. Any frequency higher than that would involve larger antennas, which, in addition, would have to be pointed. I think you can see the rather difficult problems that an aircraft would have constantly changing its antenna just to keep it pointed at the satellite. Another very interesting technical point which will determine the sort of signal design that we could use with satellites is that we have to allow for multipath propagation over water. Later I will have a little bit more to say about that aspect. Last, there is an ecology issue with the radio spectrum. The usefulness of the VHF and UHF bands for air-to-ground communications and other types of communications has been recognized for quite a while, and it has become a very crowded portion of the frequency spectrum, so that we will have to be careful to allow shared usage and not to dominate the band.

A number of experimental programs aimed at solving a number of problems suggested by these characteristics have been conducted in the past. I mentioned NASA's ATS-I satellite which was used for tests between some commercial airliners and a ground station. I have been more involved with the Lincoln Experimental Satellites and the ground equipment that has been used with them. The Lincoln Experimental Satellite (LES-III) was used for propagation measurements, trying to investigate the mechanism of how signals would propagate from very high altitudes down to an airplane. LES-V and -VI were communication satellites; they demonstrated with our ground equipment, which we call the Tactical Transmission System (TAT), that a number of multiple-access techniques or a large number of users could efficiently use these rather simple satellites. Figure 4 indicates just what one of these satellites looks like. The satellite is on the left, in this case, the LES-VI. It is the most recent of the Lincoln Satellites, and it was launched about 3 years ago. It broadcasts in the UHF frequency band, the band which could easily be used on aircraft, ships, or any other sort of small terminal. Just a few quick items of interest on the satellite are: the dark blue material wrapped around it are actually the solar panels; the sun's energy hits the solar panels and generates roughly a kilowatt of raw dc power, which is converted into radio-frequency energy and is transmitted by the small antennas shown. Another benefit of using this lower frequency band is that the satellite, itself, is quite simplified.

Figure 5 shows what the inside of LES-VI looks like. What appears to be gold-covered boxes is just that: they are boxes with a very thin gold coating on the outside for excellent thermal and electromagnetic shielding. As a matter of fact, the thermal shielding is so good — after very careful design — the electronics inside these boxes actually stay at room temperature, plus or minus a few degrees. Considering the extremely hostile environment in space, that says quite a bit about the thermal design engineers.

What does one of these satellites do? Its function is very simple: it just listens to signals on a given frequency band, amplifies anything that comes in on that band, then moves those incoming frequencies to a slightly different frequency, amplifies them, and broadcasts them out again. You have to change the frequency a little bit, because if the satellite broadcasts on the same frequency that it receives on, it would just be talking to itself and get caught up in the loop. As a result, it would just sit there and behave like a bit oscillator — a very expensive one, too. LES-VI, as a matter of fact, was the very first of the automatically stationkeeping synchronous satellites. This meant that without commands from ground stations, LES-VI remains hovering over one point on the earth. Previous synchronous satellites required ground commands for stationkeeping. Figure 6 depicts, in a rough way, how LES-VI did that. It depicts the earth and the pointing direction to the sun. As we all know by now, a synchronous satellite always stays above one point on the earth because as the earth rotates, so does the satellite. The satellite senses the sun and the earth, and if it knows what time it is, it knows where the sun and the earth ought to be. If they are not sensed where they should be, the satellite moves itself slightly by applying a sharp electrical pulse to a little piece of Teflon-type material, which vaporizes slightly and causes a plasma jet to move the satellite over, just a little bit, until the error is corrected. The satellite, in order to make its orbit even more stable, spins around itself at about 8.5 revolutions per minute as it slowly moves around its orbit about the earth.

Figure 7 shows one of the problems with this sort of spin-stabilized satellite. For greater efficiency, we would like to be able to broadcast our energy in a fairly narrow beam toward the earth. Why broadcast energy all over into space when you just want the energy beamed down to earth? LES-VI used a so-called electronically despun antenna system. This system activates only those antennas which are looking at the earth at any instant of time. The electronics, thus, switch between antennas at just the right rate to compensate for the spin of the satellite, so LES-VI is always looking down at the earth. The fascinating thing about this is that LES-VI actually generates only about 50 watts of radio-frequency power, or one-half the amount of power in a light bulb. This beaming adds another effective factor of 10, so altogether LES-VI is broadcasting only 500 watts down toward the earth but it can serve a significant number of users. I always find that analogy between satellites 22 000 miles up and light bulbs rather amazing.

Now that our satellite has been established in orbit, how do we go about using it? The straightforward way of using the satellite bandwidth, as shown on Figure 8, is to assign channels, similar to the way the spectrum is chopped up for television, radio, or whatever, and to use certain simple modulation techniques, AM or FM. One difficulty with this is that there may be only a few channels, yet very many users, so that we have to figure out a good way to assign the users to the channels on a dynamical basis. It would not be advisable to allocate a fixed frequency to one user because he would keep too much of the satellite occupied. Another interesting problem with frequency-division multiple access is shown in the next slide (Fig. 9). Multiple access means access to the satellite from a multitude of terminals.

Figure 10 shows what the effects of reflective propagation can be. We have a multipath interference pattern where the received power on some frequencies is very low compared to the received power on other frequencies, depending on whether the reflected rays just cancel out the direct rays or whether they actually add to them. That is one problem with frequency-division multiple access, if we consider airborne users. Obviously, ships and other stations that are physically on the ground do not have this problem. One way around that is shown in Figure 11. Instead of assigning people to certain frequencies, we assign them certain slots of time, actually very short slots of time, quick bursts of perhaps a one-millionth or a ten-millionth of a second, and each user takes his turn with his burst. This system is called time-division multiple accessing. Instead of splitting frequency up, we divide time into intervals. However, if you send a very short pulse it will cover, all by itself, the whole frequency band. This system, thus, has the same problem of the echo — echo from channel 1 clobbering channel 2 — and also the dynamic assignment problem.

A third technique (Fig. 12) is called code-division multiple accessing. Here every user is given some frequencies and some times; he transmits on a random pattern, at least, it appears random, and the person that he is trying to talk to is always looking for that type of pattern. With this pattern, we can let everybody talk on top of themselves, while the signals from other people tend to look like noise to the one particular link that is being received from. A particular system, TAT, was developed at Lincoln Laboratories and was pursued by the military. Basically it is a code-division multiple access system, as shown in Figure 13 in block diagram form. Modem, meaning a modulator/demodulator, is the thing that takes the input data and somehow converts them into a signal ready to be used; it is a very fast frequency synthesizer. Thus, the signal can hop from frequency to frequency, covering the whole band. The frequency synthesizer puts out one of a million frequencies and changes frequencies in about ten millionths of a second. By generating a hopping pattern it becomes possible to spread those little bits of energy over the bands and to get around the multipath problem and around the multiassignment problem.

Figure 14 shows a little more specifically what this band spreading, the way you make each and every individual signal cover the whole band in time, would look like. Each user transmits on some sort of a pattern by changing the frequency of the information slightly as he is making these great big hops across the bands. It is called the frequency-hopping type of a multiple access system.

Figure 15 indicates what sort of performance we can get with this system. If we plot the number of people that can use the satellite simultaneously versus the signal-to-noise ratio — and the signal-to-noise ratio is very high — we could get on the order of a dozen high-rate users, certainly not high in the sense of gigabits, but high in the sense of needing only 2400 bits per second to transmit one voice conversation. On the other hand, if these mobile users were satisfied with 75 bits per second, which is more typical with teletype rates, we can get a factor of 32 more users to a satellite. Of course, there is a message here, namely, to make most efficient use of the satellite bandwidth that is available, it would be best if these mobile users were using the lowest data rates that they could possibly get away with. Does an airliner over the ocean really have to talk to his control tower or can he simply teletype his position? This is something to be looked into.

Figure 16, on the TAT system, shows just how big this modulator/demodulator actually is. Depicted is a prototype the Lincoln Laboratory built, consisting of two drawers of equipment and a control panel. When everything is put together, it is really smaller than a television set, and all the operator has to do is to key in his little hopping pattern, which determines how his signal is going to be spread across the band. Or he enters the receive pattern, which determines what signal he is looking for, punches a button or two, and is ready to go. Sylvania built a number of production models of this Modem for the Government, and they got it down to one drawer. Most of the equipment shown on the top of this box are small digital integrated circuits. There seems to be one thing in the country where the prices are dropping and that seems to be digital integrated circuits. That, I would say, is the trend of the future in terms of communication; it will be digital.

Up to now, we have talked only about communications for mobile users. Navigation is also a very clear application of satellites. Since those satellites are always up there in some constellation, why not take advantage of them to find out where you are? Figure 17 indicates the basic way. Basically, there are three transmitters: transmitter zero is a reference and transmitter 1 and transmitter 2 are radio transmitters. The receiver listens to the time delays of the transmissions from transmitter 2 relative to the base and transmitter 1 relative to the base, and these generate so-called reference hyperbolas for a navigation system. The next slide (Fig. 18) shows how you can actually use this information. If I am a receiver, and I know that I am in the same geometric plane as the three transmitters or on the surface of the earth (it just complicates the geometry a little bit more), and if I know that the relative delay between these two transmitters is $\Delta T_2$ or whatever, that tells me I must be on a hyperbola, and if I know the delay between the other two, it tells me I must be on a second hyperbola. If I am on both hyperbolas, I must be at the crossover point. Fundamentally, all radio navigation systems work this way. A rather elegant application of this sort of technique was developed by Johns Hopkins University for the Navy which was called the Transit Navigation System, as indicated in Figure 19. Instead of having three transmitters, why not have one satellite going around so quickly that it might as well be three satellites? Thus, they put the transit satellite about 600 miles above the earth, in a polar orbit. If I am a ship and willing to wait essentially in one position for a couple of minutes, I can have the benefit of three different transmissions. Johns Hopkins developed some rather clever techniques for the ship to measure the distance that the satellite has gone in orbit. From the three points and from the knowledge where the satellite is, the ship can at once tell where it is — to within a very small fraction of a mile to within hundreds of feet. This systen has been in use for quite a while and has worked exceedingly well.

Knowing your position to within hundreds of feet implies that you know the satellite's position to within some hundreds of feet. However, we are dealing with some very interesting geophysical interactions since the satellite does not travel in a perfectly circular orbit. The earth itself is not perfectly circular and the satellite is drawn a little this way and a little that way. Thus, in doing this experiment they learned quite a bit about the shape of the earth.

How about future applications for navigation satellites? One area, aside from the obvious one of letting a ship or plane know where it is, will be in air traffic control. One of the problems is to let someone else know where you are. Figure 20 shows how such a system could work. In order to get its position, the airplane needs four satellites, not just three, as the ship. The ship knew it was on the surface; the airplane has the fourth variable of altitude. If it knows its altitude exactly, it can get away with three satellites, but if it has one more unknown, it needs one more satellite position. We can picture a constellation of four satellites, for instance, that either beam down to the airplane which then makes those hyperbolic calculations that I mentioned, or the airplane could transmit up to the four satellites and down to a ground station. The ground station could do all the calculations for it and transmit back again. There are all sorts of permutations and combinations on this. At least, the figure indicates the idea.

In conclusion, I have tried to relate some of our past efforts in communication and navigation and to indicate some future developments that we might be able to expect in this very fertile area in which space technology can really benefit us in finding some solutions to these very down-to-earth problems.

Transcribed from tape

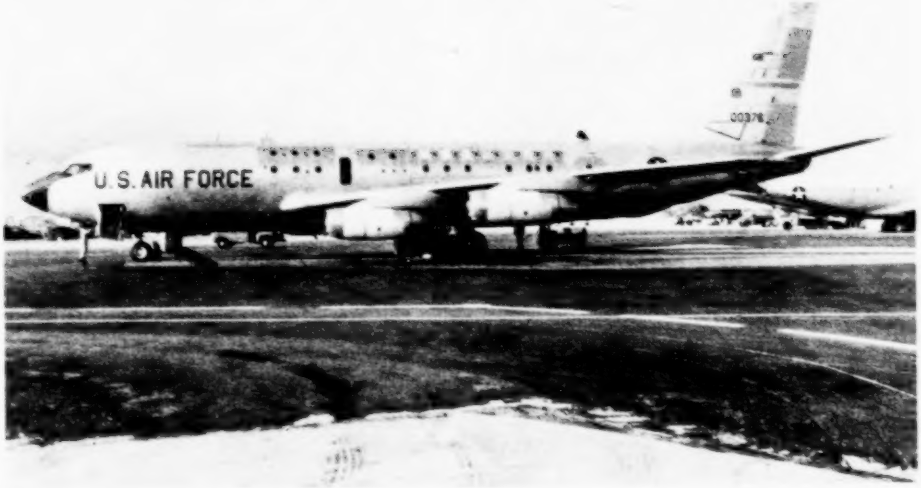


Figure 1. KC-135 with blade antenna for satellite communication.

- Airline Transoceanic Communication
- Reliable Long-Range Ship-Shore Communication
- Emergency Communication in Regions With Rough Terrain
- Military

Figure 2. Some applications of satellite communication for mobile users.

- Large Number of Intermittent Users
- Equipment Must Be Easy to Use and Inexpensive
- Operating Frequency Must Allow for Simple Antennas on Terminals
- Must Allow for Multipath Propagation Over Water
- Must Be Compatible With Other Electromagnetic Spectrum Allocations

Figure 3. Characteristics of satellite systems for mobile users.

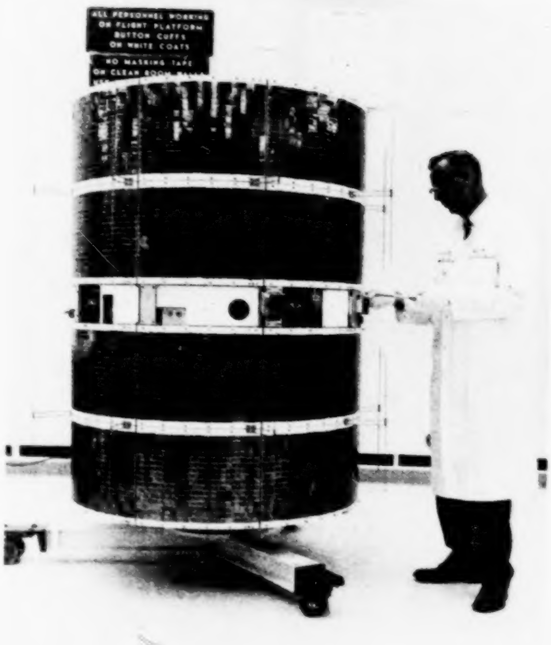

ALL PERSONNEL WORKING ON FLIGHT PLATFORM BUTTON CUFFS ON WHITE COATS
NO MASKING TAPE ON CLEAN ROOM WALLS

Figure 4. LES-VI external view.

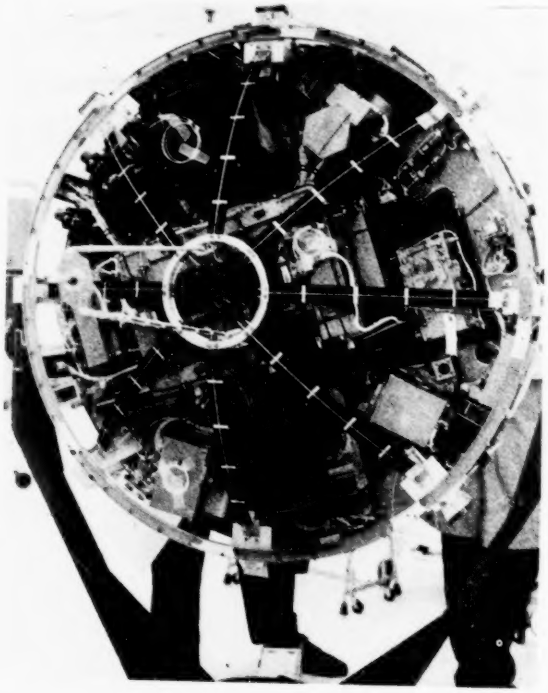


Figure 5. LES-VI internal view.

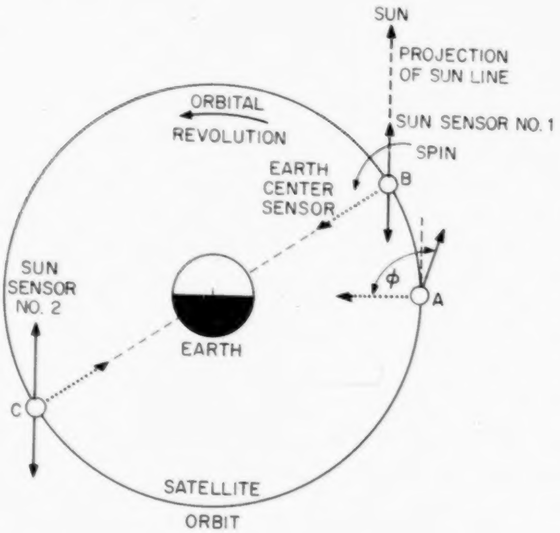

SUN
PROJECTION OF SUN LINE
ORBITAL REVOLUTION
SUN SENSOR NO. 1
SPIN
EARTH CENTER SENSOR
B
SUN SENSOR NO. 2
$\phi$
A
EARTH
C
SATELLITE ORBIT

Figure 6. Determination of satellite position.

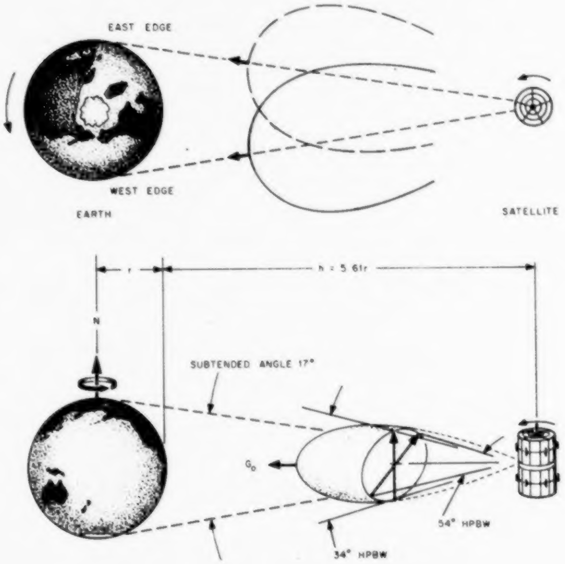

EAST EDGE
WEST EDGE
EARTH
SATELLITE
r
h = 5.61r
N
SUBTENDED ANGLE 17°
$G_0$
54° HPBW
34° HPBW

Figure 7. LES-VI antenna patterns.

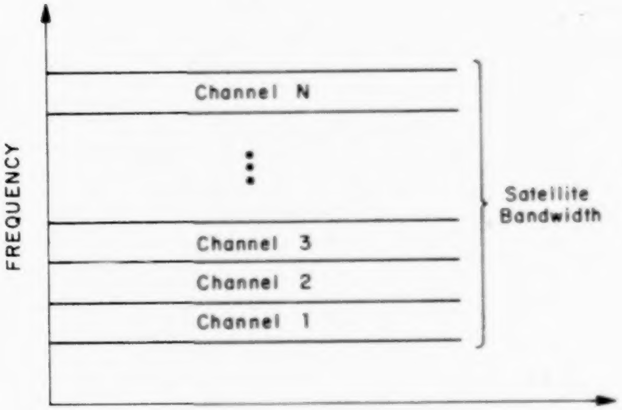

FREQUENCY
Channel N
Channel 3
Channel 2
Channel 1
Satellite Bandwidth

Figure 8. Frequency-division multiple access.

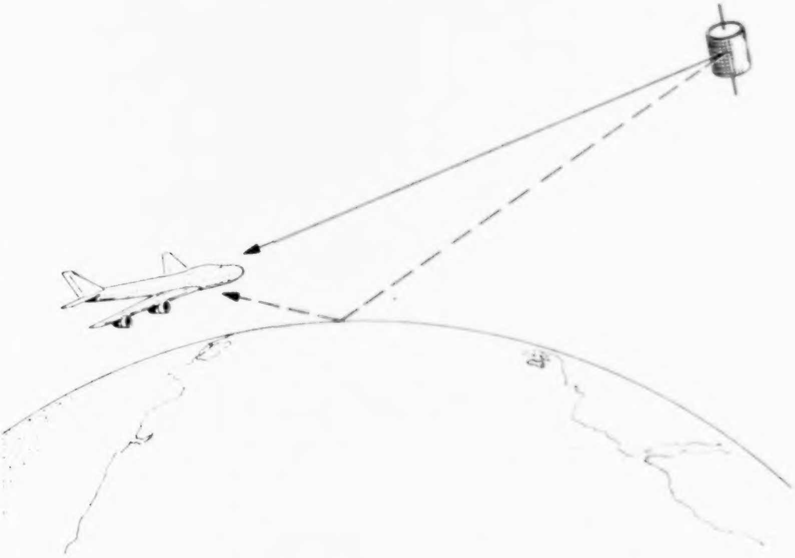


Figure 9. Multipath progagation.

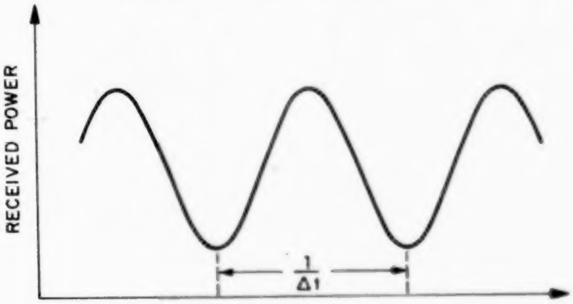


Figure 10. Multipath interference pattern.

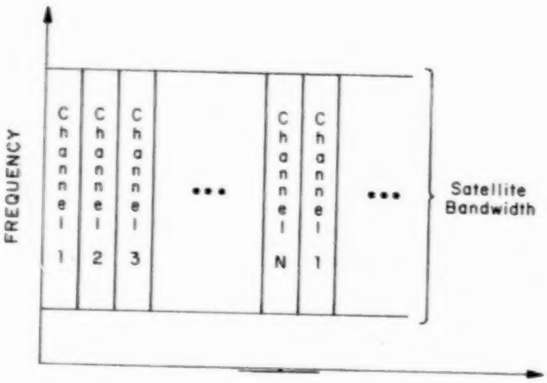

FREQUENCY
Channel 1
Channel 2
Channel 3
• • •
Channel N
Channel 1
• • •
Satellite Bandwidth

Figure 11. Time-division multiple access.

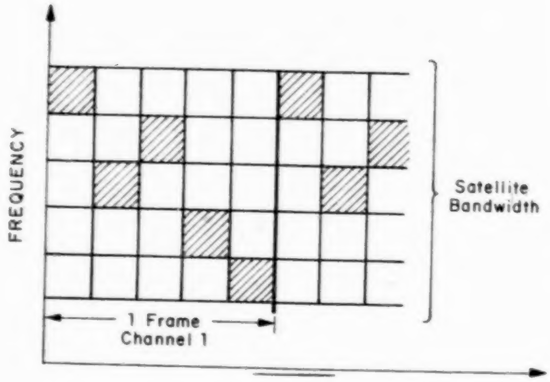
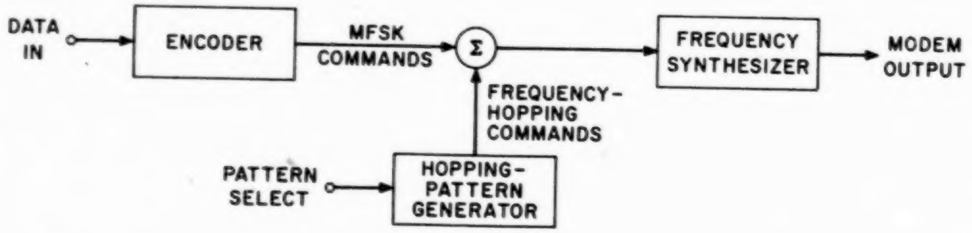
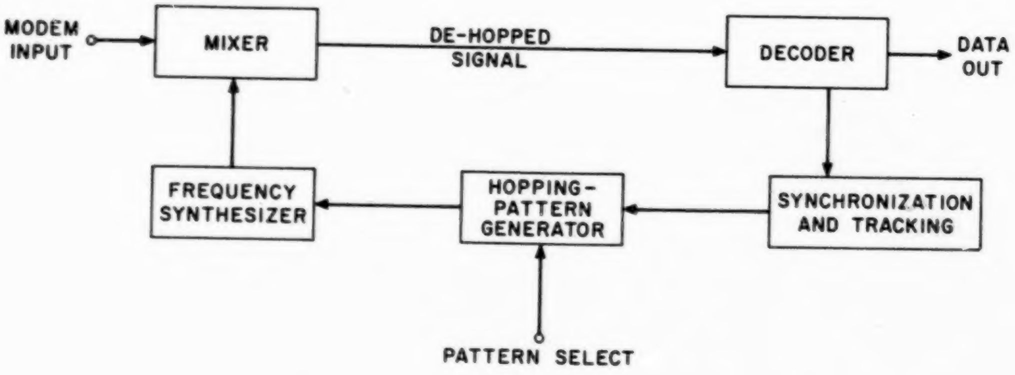

FREQUENCY
Satellite Bandwidth
1 Frame
Channel 1

Figure 12. Code-division multiple access.


DATA IN
ENCODER
MFSK COMMANDS
Σ
FREQUENCY SYNTHESIZER
MODEM OUTPUT
FREQUENCY-HOPPING COMMANDS
PATTERN SELECT
HOPPING-PATTERN GENERATOR

(a) TRANSMITTER


MODEM INPUT
MIXER
DE-HOPPED SIGNAL
DECODER
DATA OUT
FREQUENCY SYNTHESIZER
HOPPING-PATTERN GENERATOR
SYNCHRONIZATION AND TRACKING
PATTERN SELECT

(b) RECEIVER

Figure 13. TATS Modem block diagrams.

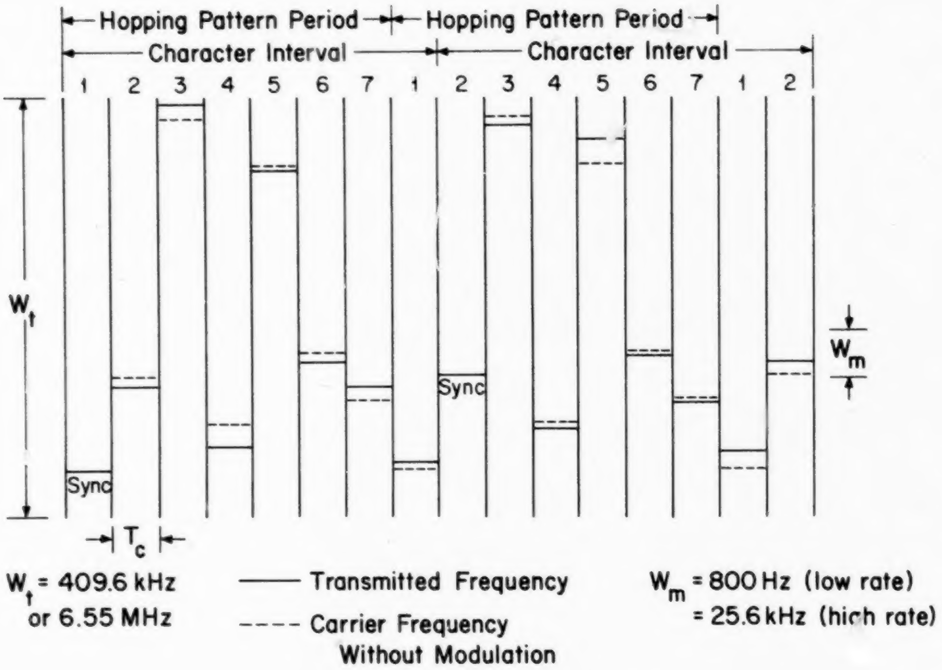

Hopping Pattern Period
Hopping Pattern Period
Character Interval
Character Interval
1 2 3 4 5 6 7 1 2 3 4 5 6 7 1 2
$W_t$
$W_m$
Sync
Sync
$T_c$
$W_t$ = 409.6 kHz or 6.55 MHz
Transmitted Frequency
Carrier Frequency Without Modulation
$W_m$ = 800 Hz (low rate) = 25.6 kHz (high rate)

Figure 14. TATS bandspread signal format-fixed pattern.

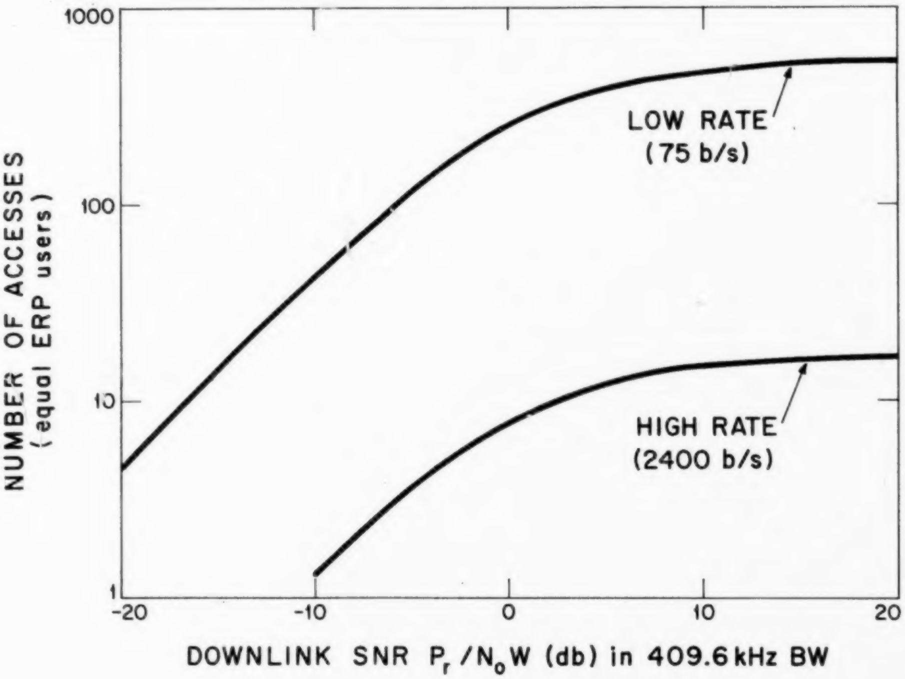


Figure 15. TATS multiple access capacity.

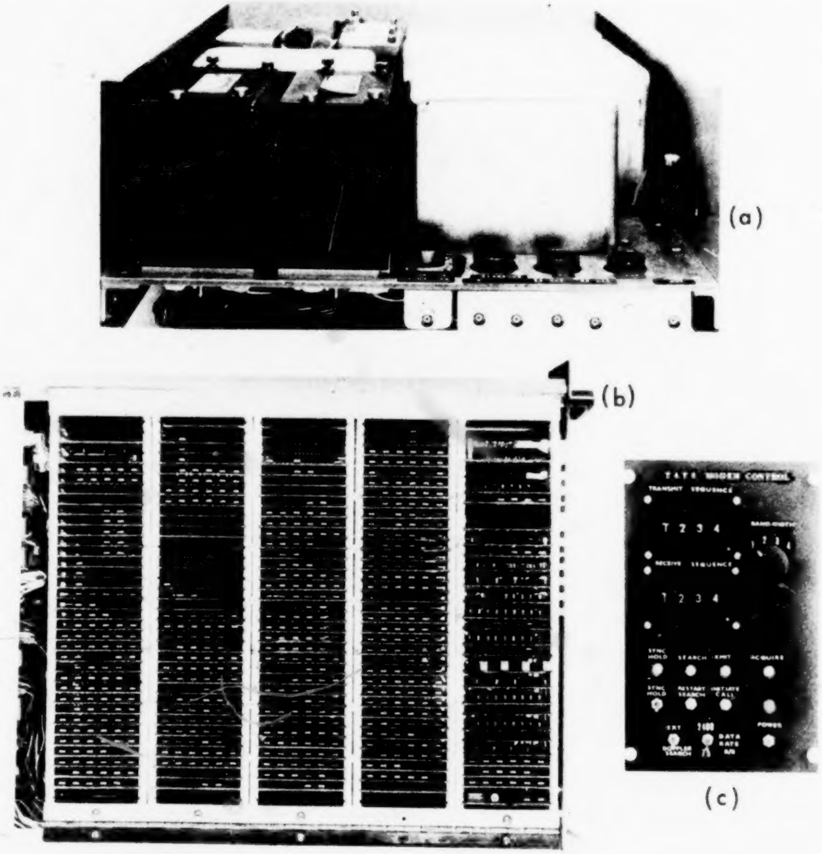

(a)
(b)
(c)
TATS MODEM CONTROL
TRANSMIT SEQUENCE
1 2 3 4
RECEIVE SEQUENCE
1 2 3 4
SYNC HOLD
SEARCH
XMIT
ACQUIRE
SYNC HOLD
RESTART SEARCH
INITIATE CALL
EXT
2400
DOPPLER SEARCH
DATA RATE
POWER

Figure 16. Lincoln Laboratory prototype TATS Modem.

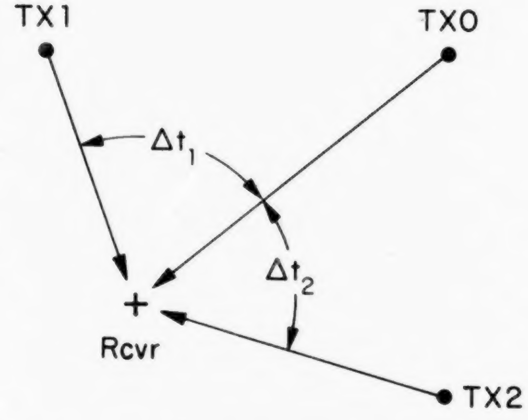

TX1
TX0
Δt1
Δt2
Rcvr
TX2

Figure 17. Radio generation of reference hyperbolas for position finding.

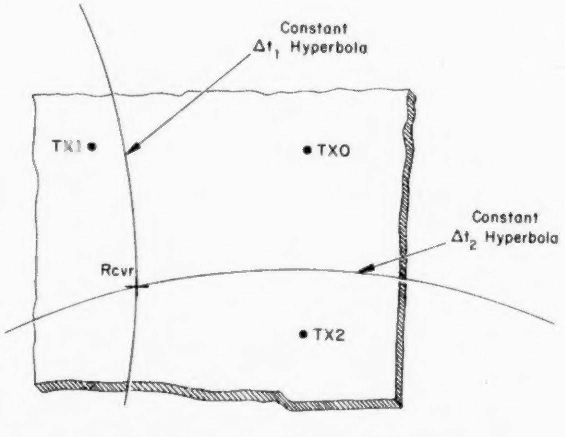
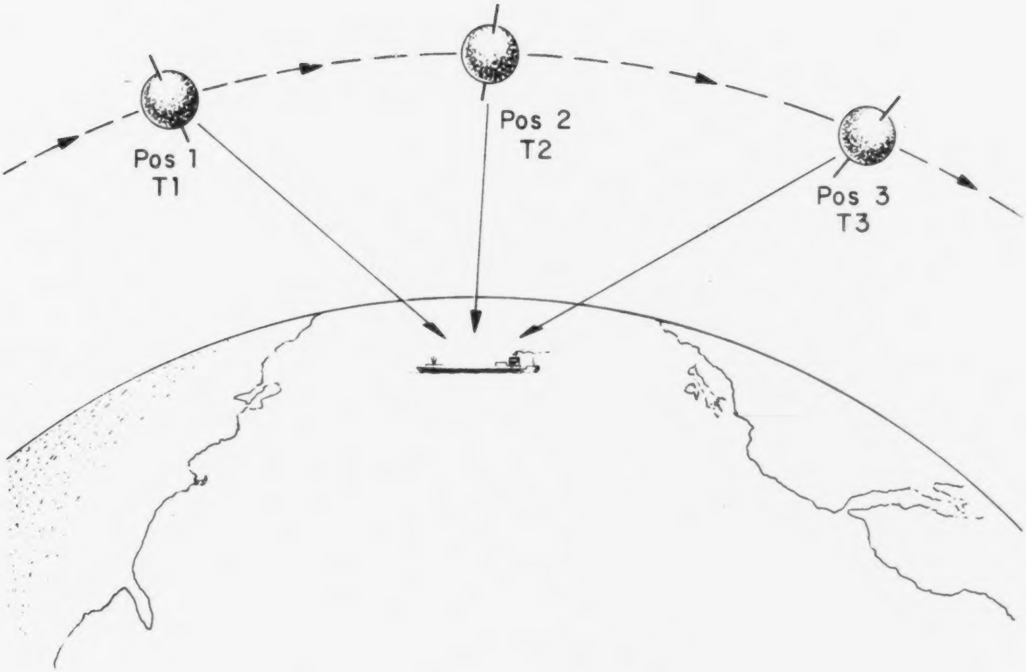

Constant Δt1 Hyperbola
TX1
TX0
Constant Δt2 Hyperbola
Rcvr
TX2

Figure 18. Hyperbolic position finding.



Pos 1
T1
Pos 2
T2
Pos 3
T3

Figure 19. Transit navigation satellite concept.

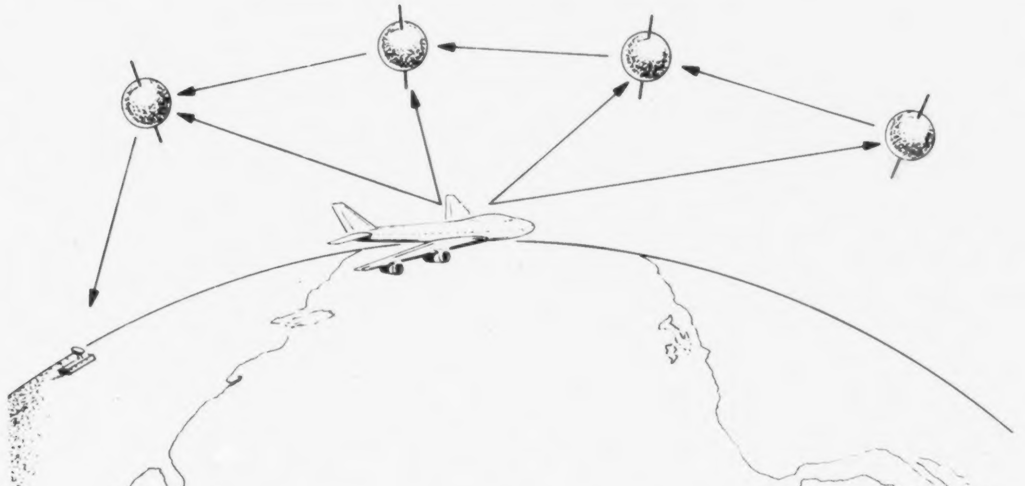


Figure 20. Aircraft navigation satellite system.

# A NEW DEVICE
# FOR COMMUNICATION SYSTEMS

By R. R. Beck
Page Communications Engineers, Inc.
Washington, D.C.

## Introduction

In the Government it is often desirable for a communication system to provide additional features other than the normal transfer of information from point to point. These additional features may be any or all of the following:

1. Provides distance between the transmitter and the receiver (communication ranging)

2. Provides locations of the transmitter or receiver (communication navigation)

3. Provides operation in a common frequency allocation in a manner which allows multiple user communications (random multiple access)

4. Provides user identification

5. Provides Doppler shift correction (correction of frequency offset, induced by differential velocities of moving transmitter or receivers)

6. Provides tolerance to external interference.

In order to provide these features the communication system must have a special modulation structure. Phase coherent frequency-hopping (FH) modulation is a prime candidate technique for providing a multiple feature, flexible communication system. The Phase Coherent Frequency Synthesizer, recently developed by Page and the Naval Research Laboratory, provides the modulation source for such a communication system. This paper will describe this type of synthesizer and its system uses.

## Synthesizer Description

A frequency synthesizer is a single generator that produces any one of a multitude of possible signals. Each signal or frequency is precisely controlled, and the control is usually in steps rather than being infinitely variable. The frequency and the duration of the frequency period can be locally or remotely controlled. Figure 1 shows a frequency synthesizer in its simplest form.

The two basic characteristics of the Phase Coherent Frequency Synthesizer which make it different from the more common industrial variety synthesizers are its phase/frequency coherence and its fast switching or phase setting time. These two characteristics allow the synthesizer to produce combined phase and frequency-hopping modulated signals.

An explanation of the operation of the Phase Coherent Frequency Synthesizer must first begin with a definition of "phase coherent frequency." Phase coherent frequency is defined as a frequency that has phase continuation from one appearance to another. An example of this type of coherence would be a frequency standard that has its output switched on and off in alternate fashion. Each time the frequency appears at the output of the switch, its phase is the same as if the switch had remained in the closed position (Fig. 2). The word "phase" means relative position of the signal (usually measured in degrees). This coherency also requires that the multiple synthesizer output frequencies are all separated by exactly the same frequency, and the phases are all related to a common frequency source; in this case, an internal or external frequency standard. This means if the source frequency is changed by a certain percent frequency or phase, all output frequencies will change by that same percent. The precision of the frequency separation is proportional to the stability of the frequency standard and the quality of the synthesizer design.

The Phase Coherent Frequency Synthesizer can be generally described by the following characteristics [1]:

1. Dual modulation capability (phase and frequency Hopping)

2. 256 VHF output frequencies (television RF spectrum)

3. Fast frequency hopping

4. Ultrafast transitions from one frequency period to the next.

5. Ultrasmall component of noise contained on the output frequency

6. Ultrastable frequency steps

7. Ultrastable frequency repeatability

8. Phase continuity from one frequency appearance to its following appearances (coherence)

9. Local and remote control of phase, frequency, frequency-hopping rate, phase rate, and frequency or phase duration period.

If you had a super television set at some time in the future that had 256 channels that had to be switched from channel to channel at the frame rate for reception, your television might have a coherent synthesizer for tuner local oscillator.

The 256 frequencies are generated by multiplying the outputs for two groups of 16 oscillators, each of which is referenced back to the internal frequency standard. Each of these groups supplies 1 of 16 possible outputs. The 1 of 16 selection process is provided by a 16-pole electronic switch and is controlled by either a random encoder, front panel switches, or a remote source (computer). Thus, the 16-by-16 cross-matrix of stable frequency sources produces 256 output frequencies by using all combinations of the matrix. A simple block diagram of a Phase Coherent Frequency Synthesizer is shown in Figure 3.

A simple analog of the Phase Coherent Frequency Synthesizer would be a 256-position, single-arm switch connected to 256 different frequency standards. Each of the standards would be referenced or locked to a common frequency standard. The switch could jump from one position to any other position almost instantaneously. The mechanism which controls the switch position time is also locked to a reference frequency standard. The output of the synthesizer is the arm of the switch.

## Synthesizer Features

The Phase Coherent Frequency Synthesizer, when properly incorporated into a communication system, will be able to provide normal communications plus the following characteristics:

1. Noise resistance

2. Multiple users in common bandwidth

3. User identification

4. Ranging (transmitter to receiver distance measurement)

5. Navigation

6. Doppler (motion-induced frequency distortion) correction

7. Communication privacy.

The noise tolerance or resistance is provided when a narrow-band data signal is spread over a wide bandwidth. The information rate of transfer is reduced while signal reception quality increases when FH modulation is used to spread the data bandwidth. This is a very important characteristic for types of communication where there is a possibility that some outside source will try to intentionally confuse the system receiver with fictitious signals. The civil police, the FBI, and various government agencies will all have requirements for this type of reliable communications.

The sequences in which the various synthesizer output frequencies are arranged can be made to be unique or different from one another. This characteristic allows each user to be assigned a particular sequence which cannot be confused with one of the other system user's sequences. When the receiver is set to accept a certain input sequence and data are received at that setting, the receiving operator knows for certain that the incoming data are from the desired party (user). The number of users the system can support is proportional to the number of different synthesizer frequencies that are available. Thus, the system's coded frequency sequences provide multiple-user operation, user identification, and communication privacy.

The ranging or distance measuring feature of the FH communication system can be provided by measuring the time required for a signal to traverse from the transmitter to the receiver (simplex mode) or from the transmitter to the receiver and back to the transmitter (transpond mode). A coded sequence is the time identifier. In the transpond mode, the time is measured between the first-sequence appearance at the transmitter and second-sequence appearance at a colocated receiver. The third appearance of this sequence can be made sufficiently long so as not to be a consideration. The accuracy of the time measurement, and, thus, the distance measurement, is enhanced by the coherent feature of the signal structure. Figure 4 shows the conventional pulse-to-pulse ranging operation versus the coherent waveform ranging operation. The conventional measurement is degraded by the variation in the receiver's signal shape and width. The coherent technique makes an average measurement over the individual cycles of the carrier. This provides higher resolution and therefore greater accuracy.

Navigation data can be extracted from the coherent FH system by means of the same features that are used for ranging. The system that requires navigational data and has the restriction of omnidirectional antennas or all-direction antennas must perform range measurements from several points of observation. These multiple range data are used to plot circles of possible location. The intersection of the multiple circles provides the location of the specific transmitter. The minimum requirement would be three observation points in a triangular sector. Two points may be used if additional location information (such as forward or backward direction data) is available. Single reference-point direction-finding systems require rotating directional antennas or a multitude of antennas forming a circular array.

The coherent feature of the FH also provides an aid to correcting frequency offset distortion. This distortion occurs in a communication link when the transmitter and receiver are in relative motion and is attributed to the Doppler effect. Since all the frequency periods are phase continuous and phase related, a phase comparison of every frequency period can be used to correct the common clock. This is not possible if the system frequency source (the synthesizer) is noncoherent.

## Synthesizer Application

A typical incorporation of the synthesizer into a communication system is shown in Figure 5. At the transmitter the synthesizer serves as data to RF signal-converting device. Its output is amplified and, in some cases, raised in frequency and then applied to the transmit antenna. At the receiver the synthesizer serves as the local oscillator. The RF receiver, the intermediate frequency (IF) decoder circuit, and the signal synchronizer circuit work in conjunction with the synthesizer to derive the data which were originally put into the system at the transmitter.

When the coherent synthesizer is incorporated in a FH/phase modulation system, the resultant feature allows a wide variety of system applications. The noise tolerance feature increases the effective signal-to-noise margin at the receiver. This feature will allow a system to:

1. Operate with more noise and interference than a common system

2. Operate with increased system range (communication distance) when the interfering noise is not present, or

3. Operate over a communication link with more path impairments (multipath, rain attenuation, etc.) than that which is possible with a common system.

These characteristics are necessary for top priority communication channels.

Communication satellites which are designated as repeating devices are particularly prone to external interference. As the earth's communication activity and spectrum crowding grow, satellite communications will experience larger amounts of man-made interference. The use of a coherent FH system can considerably improve the tolerance to this interference.

Phase-coherent FH modulation could also find use as an emergency backup communication system for air-traffic control. This backup system would come into operation when adverse communication conditions arise. The coherent FH modulation system in this application would be set to operate in the noise tolerance mode. This operation takes a narrow bandwidth signal and spreads the signal over a wide bandwidth (on RF spectrum). This trades off a reduction in the data rate for improving the effective signal strength at the receiver and thus overcomes external noise, self-interference, and poor transmitting conditions.

The multiple-user and user-identification features can be used in an application where a common communication point must talk to a squadron of men, a group of mobile vehicles or a group of aircraft or individuals within the latter groups. These features allow specific communication to one individual, blanking out all others. These are very common requirements.

The ranging and navigation features of the described system are required in applications where the communication uses are in strange or nebulous environments and require direction or homing information. Examples of this are ship/aircraft in a heavy fog or men in a thick jungle. Additional applications of these features are aircraft collision avoidance, automated landing in crowded airports, and tracking of suspicious individuals via planted transmitters.

## Possible Civilian or Commercial Uses

There are a number of future industrial, commercial, and civil communication systems which may utilize Phase Coherent Frequency Synthesizers and coherent FH modulation. The most prominent of these uses would be the commercial airlines air-traffic communications and police communications.

Air traffic is increasing on a yearly basis. The amount of data transfer between the aircraft and to and from the aircraft and ground is also ever increasing. These two conditions will cause new frequency channels to be required (more RF spectrum) and also cause pressure to improve the quality and efficiency of the communication systems.

Presently commercial air-traffic control communications normally incorporate a combination of human intelligence, frequency modulation communication, and radar to perform the required control and regulation functions. The future improved communication systems will have the human intelligence aided or replaced by computers, while the communications and control functions will probably be combined into an integrated system. Phase-coherent frequency hopping may form a portion of this future integrated system.

The future civil and commercial air-traffic control communication systems must provide an effective collision avoidance mechanism, an automated aircraft landing capability, an automated route setting capability, and digitized voice/data communications. This must be provided within a reasonable bandwidth. These requirements can be met by some combination of the coherent FH modulation and timesharing [2].

As crime, especially syndicate crime, grows in the U.S., the law enforcement bodies may be required to utilize sophisticated communication equipment to deter the criminal element's attempt to interrupt the police signals. Future law enforcement communications will, in most likelihood, also require: (1) message privacy, (2) multiple user (total and individual) operation, (3) user identification, (4) location information for tracking cars or individuals (range/navigation operation). A form of coherent FH modulation and its companion coherent synthesizer may be incorporated in future law enforcement communications to provide the above requirements.

## Conclusions

A new communication device and modulation capability have been developed for the transmission of digital data or voices from point to point. This device is a fast-switching Phase Coherent Frequency Synthesizer. When this synthesizer is appropriately incorporated in a communication system it can provide interference resistance, multiple-user capability, user identification, ranging, navigation, Doppler correction, and digitized communication (voice and data). This device may find extensive use in specific government communication systems which have a need for the above features. If this device and its corresponding communication system are successful for the government, civil and commercial application of similar devices and systems is very likely to take place. The prime areas of civil and commercial application are future communications for law enforcement bodies and for the aircraft/airport complex. The future law enforcement bodies' communications can take advantage of the FH system's noise tolerance, multiple user capability, and user identification features primarily, and the ranging and navigational features secondarily. The future commercial aircraft communication can take advantage of all the FH system's features for combined communication navigations, collision avoidance, automated landing, and automated route-setting. Thus, the same or similar types of communication systems that serve government satellite-to-ground or aircraft-to-ground links may also serve for the corresponding civil or commercial counterparts. In conclusion, we can say that the Phase Coherent Frequency Synthesizer and corresponding FH modulation are examples of a governmental communication development that may well benefit the average man in the street.

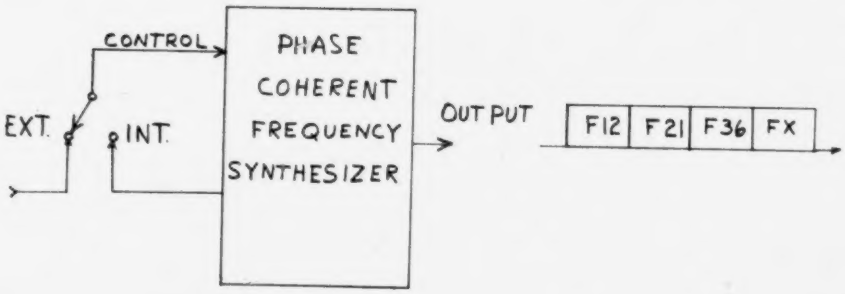

CONTROL
EXT.
INT.
PHASE COHERENT FREQUENCY SYNTHESIZER
OUTPUT
F12
F21
F36
FX

Figure 1. Phase Coherent Frequency Synthesizer, simplified.

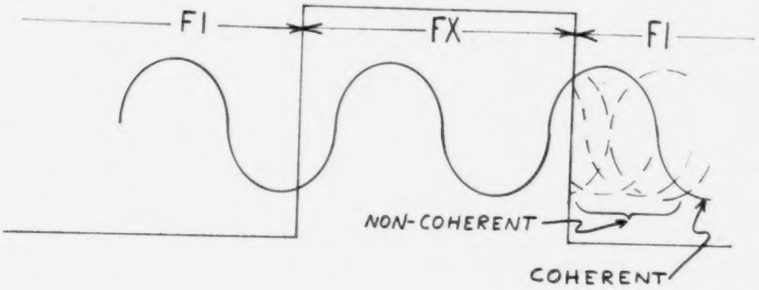

F1
FX
F1
NON-COHERENT
COHERENT

Figure 2. Phase coherent frequency switching.

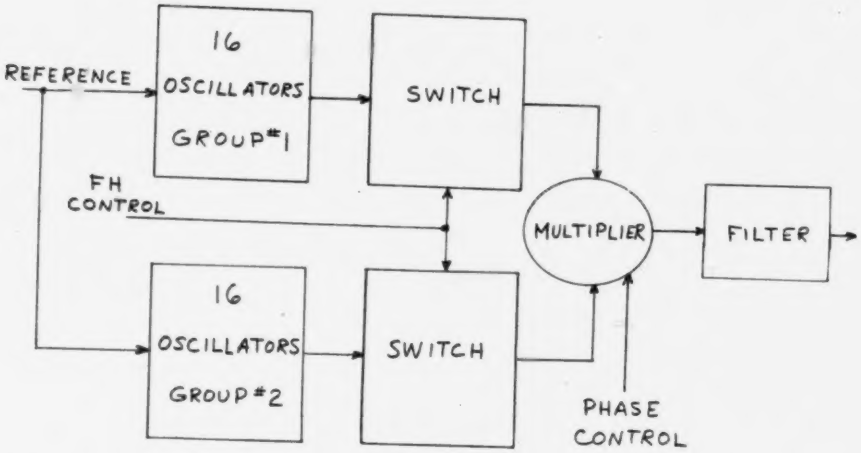

REFERENCE
16 OSCILLATORS GROUP #1
SWITCH
FH CONTROL
MULTIPLIER
FILTER
16 OSCILLATORS GROUP #2
SWITCH
PHASE CONTROL

Figure 3. Simplified block diagram of the Phase Coherent Frequency Synthesizer.

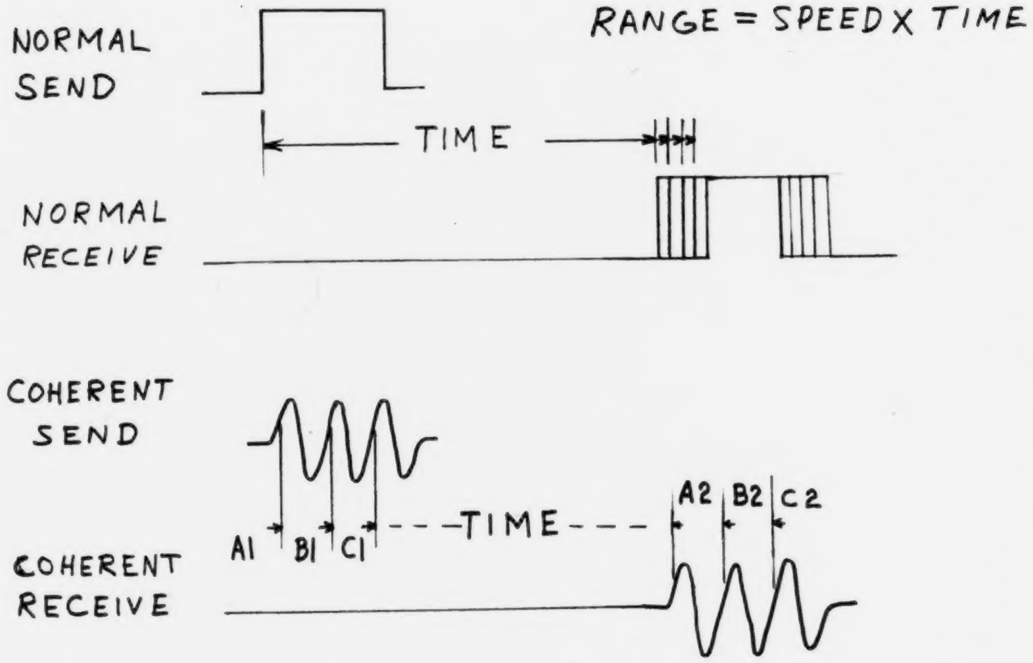

RANGE = SPEED X TIME
NORMAL SEND
TIME
NORMAL RECEIVE
COHERENT SEND
A1
B1
C1
TIME
A2
B2
C2
COHERENT RECEIVE

Figure 4. Noncoherent versus coherent ranging.

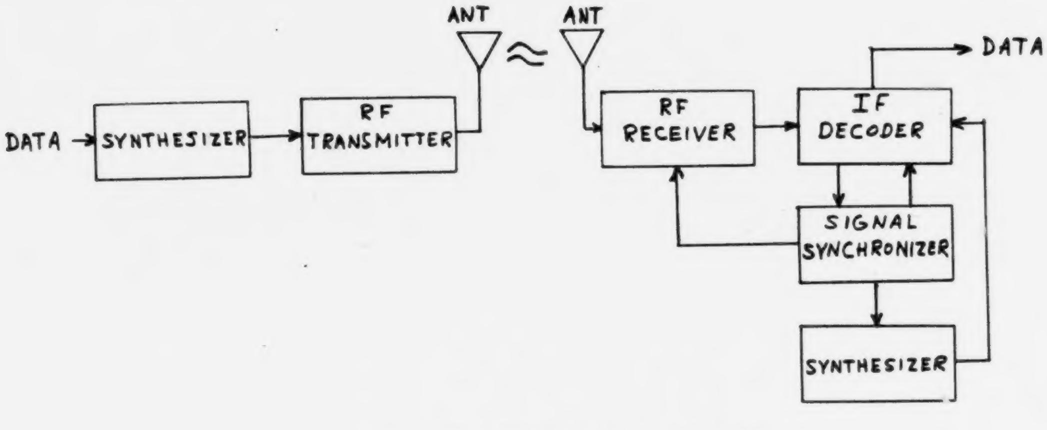

ANT
ANT
DATA
DATA
SYNTHESIZER
RF TRANSMITTER
RF RECEIVER
IF DECODER
SIGNAL SYNCHRONIZER
SYNTHESIZER

Figure 5. A simplified FH system with synthesizers.

# COMMUNICATIONS VIA SATELLITE — DIVIDEND OF THE SPACE AGE

By Gustave J. Rauschenbach
Director, Congressional Relations and Corporate Development
Communications Satellite Corporation
Washington, D. C.

Last June my daughter graduated from college, and like all proud fathers, I attended the graduation. On the way down I spent an hour or two at the Hermitage ... Andrew Jackson's home in Tennessee. One of the things that interested me was his carriage. This was the one he used to travel from Nashville to Washington, and the sign on it indicated that he considered the travel time between these two cities to average 21 days.

It is difficult to realize but if you stop and think you will conclude that in all the years, from the beginning of the world until Jackson's time, and, in fact, almost until the start of the century, man's traveling speed was tied to the speed of a horse — about 15 mph. Then, suddenly, with the coming of trains and automobiles, speeds went up to 25, then 40, then 70 mph. Next came the commercial airplane, and man's speed was again increased, starting at about 100 mph and progressing to slightly subsonic (700 mph). Soon commercial supersonic aircraft will be in the skies of the world; meantime, we have the space age. Sitting in your living rooms last summer, you saw an event that required speeds in excess of 23 000 mph to be achieved. Man made a round trip to the moon, 480 000 miles, achieved useful work, and returned all within a period of 10 days. This has been a transportation revolution.

Now, fortunately or unfortunately, not many people will ever travel at those speeds, but then there are other revolutions in which we are presently participating and still others yet to come.

Up in Washington we have a television commercial advertising bread. They draw your attention back to granny's kitchen and the old coal stove and the smell of baking bread and pie. Most of us at the Congress remember all that, but I also remember the day when our first telephone was installed. I was in grammar school, so it was not all that long ago! When this telephone was installed, my home immediately had the capability to communicate with every other telephone subscriber in the city, the state, and the country. Now, that does not say we used this capability. In fact, I remember when the telephone first started to ring — and, by the way, we all knew who it was — my aunt who lived 10 miles away — the whole house panicked. Speaking of panic, do you remember the expressions on the faces of the family receiving a telegram? It sometimes took a matter of minutes before someone had the courage to open it . . . because you knew it contained important and, sometimes, bad news. You also knew that the message had been tapped out, letter by letter, on a telegraph key, and that it had been delivered to your home from the local telegraph office by a boy on a bicycle, at a delivery speed of about 10 mph.

Well, today we are having a communications revolution. The moon landing we talked about earlier came to you "live — via satellite," and you saw that event happen with only about a 2-sec delay. That delay was in the time it took the signal to come 240 000 miles from the moon to earth, be retransmitted through a least two satellite channels, the satellites being in orbit 22 300 miles above the earth, and over approximately 10 000 miles of telephone and microwave communication link. Figures 1 through 3 show the actual setup of how the sound and picture got into your living room.

The International Telecommunications Satellite Consortium (INTELSAT IV) satellite (Fig. 4) is now being used over the Atlantic and soon to be launched in orbit over the Pacific and Indian Oceans. We have satellites over all three oceans now, but those over the Pacific and Indian Oceans are smaller and of an earlier vintage, commensurate with the requirements of those areas. The INTELSAT IV satellites weigh 3058 lb at launch. They are almost 8 ft in diameter and over 17 ft tall, and have a 9000-circuit capacity for communications, or 12 color television channels. The satellite is solar-powered and has a design life expectancy of 7 years.

The space booster (Fig. 5) is used to give the satellite a maximum speed of 23 600 mph in order to start it into synchronous orbit. The synchronous orbit means that the satellite remains motionless relative to a point on earth over which it is placed.

In other words, the satellite moves at a speed which keeps it positioned directly above a particular point on earth as the earth revolves. The Atlas Centaur launch vehicle is, of course, a development of the space age. The launch vehicle is provided by NASA, and we pay NASA at a rate determined by them for this hardware and a pro rata share of launch service cost. All the risk belongs to the Commercial Satellite (COMSAT). We pay whether the launch is successful or not!

The Causey earth station, Puerto Rico, in Figure 6 (showing antenna), the Bartlett earth station in Talkeetna, Alaska (Fig. 7), and the Paumaula earth station in Hawaii (Fig. 8) are among the largest earth stations in the total earth station complex that serves the international system. They have the capability of two-way communications.

Today there are 48 earth station sites around the world with 56 antennas in 35 countries and more earth stations are joining, literally monthly, as they are completed and join commercial operations. They will grow to 82 earth stations and 108 antennas in 63 countries by 1972.

The present international system with satellites over the Atlantic, Pacific, and Indian Oceans is shown in Figure 9. Notice that although the cable system provides point-to-point communication, the satellite services whole areas, requiring only that an earth station be provided to give access to all points within the system. The INTELSAT system satellite paths and regional coverage are shown in Figure 10. The U.S. earth stations' satellite coverage is shown in Figure 11.

I do not mean this report to be self-serving, but I feel that a few words about the international consortium, of which COMSAT is the manager, might be enlightening. The Congress, with the passage of the Communications Satellite Act of 1962, established COMSAT as a private corporation, sponsored in the United Nations by the U.S. to bring to the world the benefits of our space technology. INTELSAT (Fig. 12) presently consists of 82 nations (Fig. 13).

It is a joint venture which provides for the ownership of the satellite system on an investment-use basis. Investment-use means that each member invests in the system in proportion to its anticipated use and shares in the same proportion in any revenues generated by the system. As you would expect, the U.S., having the largest communication requirement, has also the largest investment, while smaller nations invest in proportion to their need. COMSAT represents the U.S. in INTELSAT and also manages and operates the system under contract to INTELSAT. COMSAT's revenues from international satellite communications last year were almost $70 million or a net income of $17.5 million, which works out to $1.75 a share. The important point I want to leave with you from all this is that COMSAT is a private corporation, not a government agency, and no taxpayer's money went into its establishment (Figs. 14-18).

In addition to its international interest, COMSAT has before the Federal Communications Commission (FCC) an application to provide a satellite system over the U.S. (Fig. 19). As you can see from this slide, three satellites would be emplaced over the U.S. and would provide coverage of Alaska, Hawaii, Puerto Rico, and the other 48 states. Earth stations, at least for the first go round, would be established in accordance with Figure 20.

The total cost of this system, including satellites, earth stations, etc., would run in the neighborhood of $250 million. Again, COMSAT would undertake this job without government support, using only those moneys available to any private enterprise.

Finally, as you may have heard, there exists now a requirement for an aeronautical satellite to provide better communications over the Atlantic and over the Pacific between airplanes and their ground controllers, and also eventually, airplane-to-airplane communication (Fig. 21). This program has been under consideration by COMSAT for several years. As you would expect, there exists a necessity to bring together a number of commercial companies (the airlines), the government (Federal Aviation Administration [FAA], FCC, Office of Telecommunications Policy [OTP], Department of Transportation [DOT], Department of State, etc.), and their European counterparts.

Today, our theme is to try to show that there are, in fact, desirable spin-offs from the space effort. Needless to say, the entire communications satellite system, beginning with the launch vehicle which gives the satellite the necessary speed to put it into orbit; the computers which calculate trajectories, duration, and amount of thrust, etc.; the satellite itself from its solar cells and its standby batteries; its exotic despin motor; and so forth, are all spin-offs of the space age. None of these would be available without the tremendous effort made over the past decade to place man on the moon. It is heartening to me to note that this entire sophisticated system has already paid back in some small measure in that it allowed you, the taxpayer, to watch men land, work, and walk on the surface of the moon. Much greater dividends are on the way.

Communications are growing at a tremendous rate. We program into all our planning 15 to 30 percent growth per year. It is my earnest hope that as we progress, we will succeed in bringing the world not only better communications, but better mutual understanding and solutions to worldwide problems (Fig. 22).

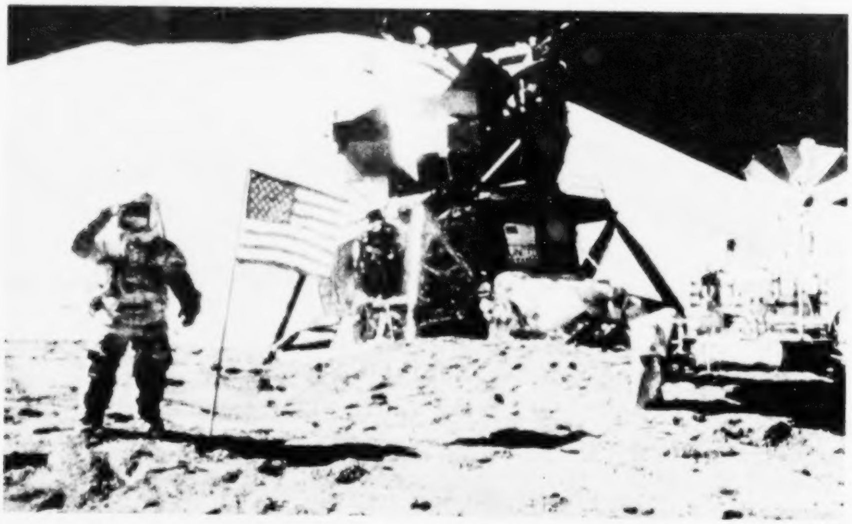


Figure 1. Apollo XV Astronaut Irwin saluting the flag.

Figure 2. Apollo XV crew on Rover.

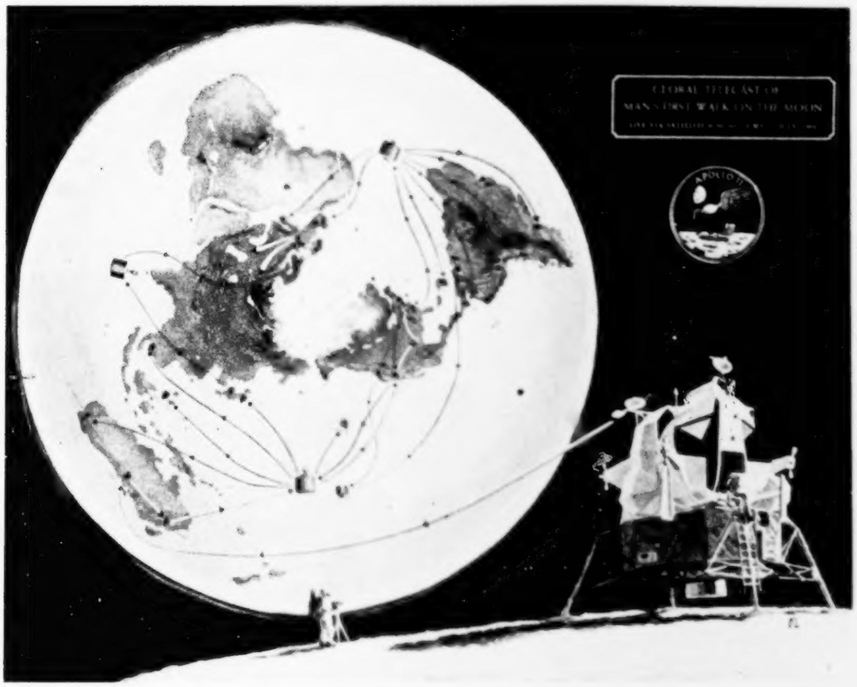

GLOBAL TELECAST OF
MAN'S FIRST WALK ON THE MOON
APOLLO 11

Figure 3. Global telecast, Apollo IX.

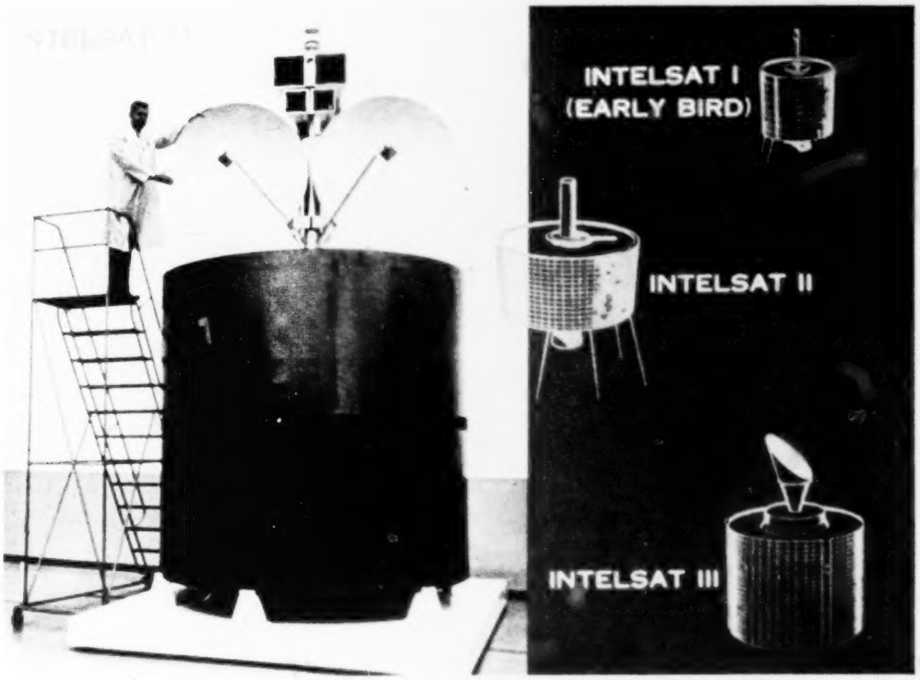

INTELSAT I
(EARLY BIRD)
INTELSAT II
INTELSAT III

Figure 4. INTELSAT-IV at Hughes with technicians on ladder.

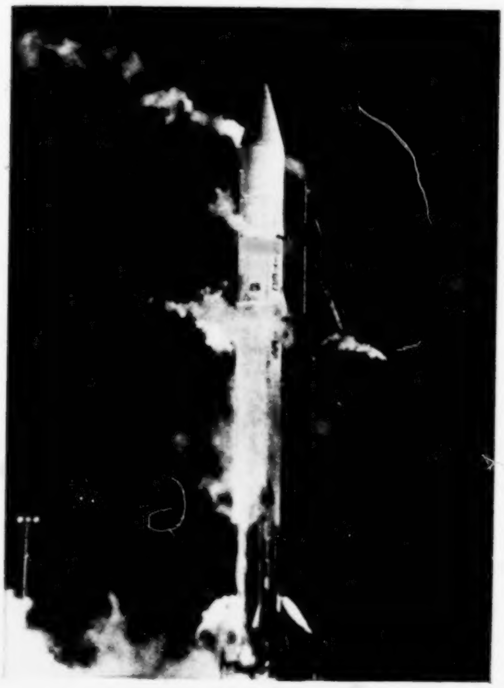


Figure 5. Launch of INTELSAT IV (F-2); Atlas/Centaur Launch Vehicle.

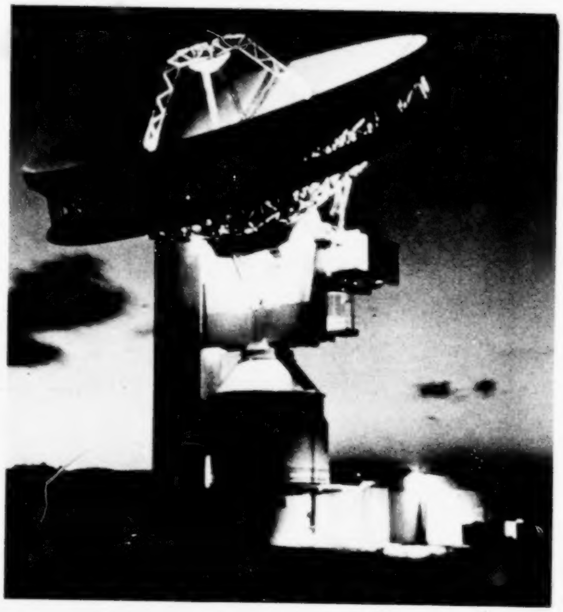


Figure 6. Causey earth station antenna.

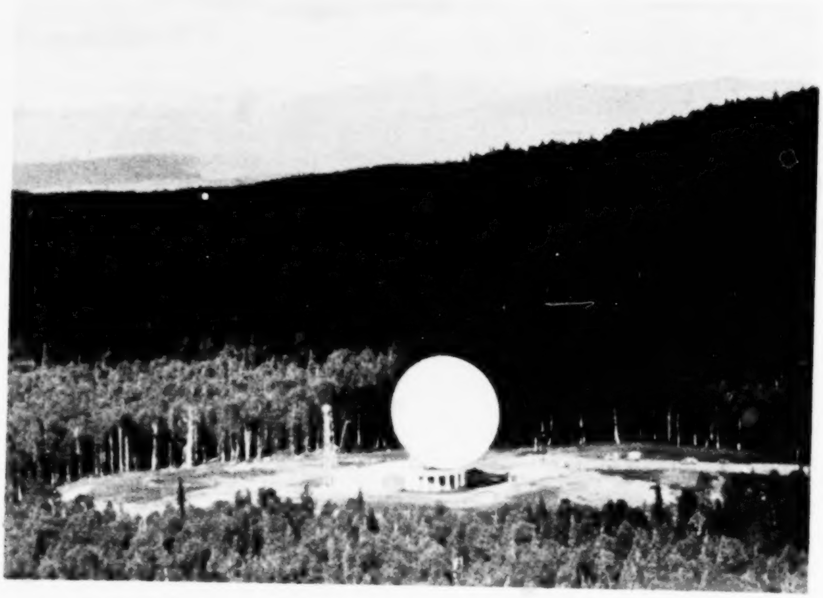


Figure 7. Bartlett earth station aerial view.

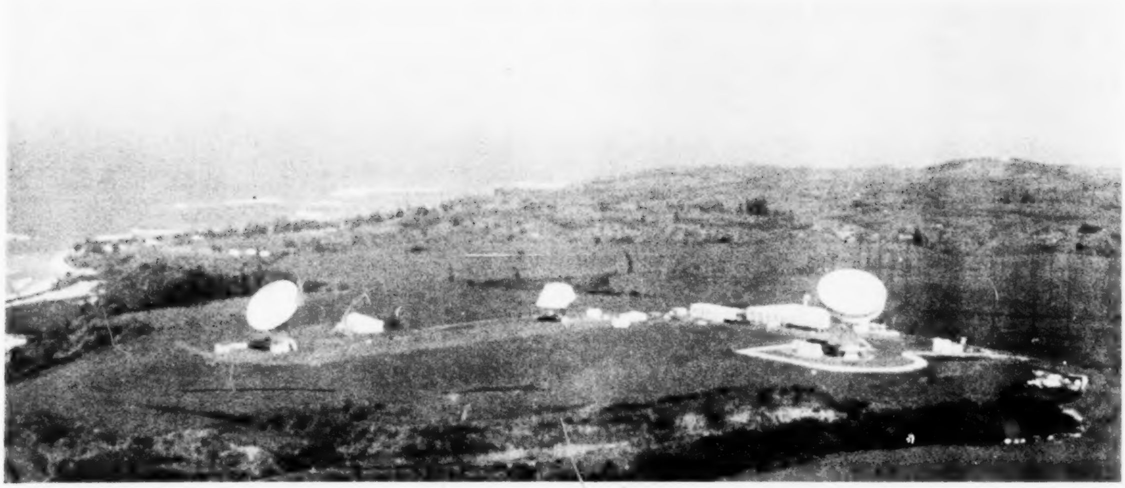


Figure 8. Paumaulua earth station aerial view 1.

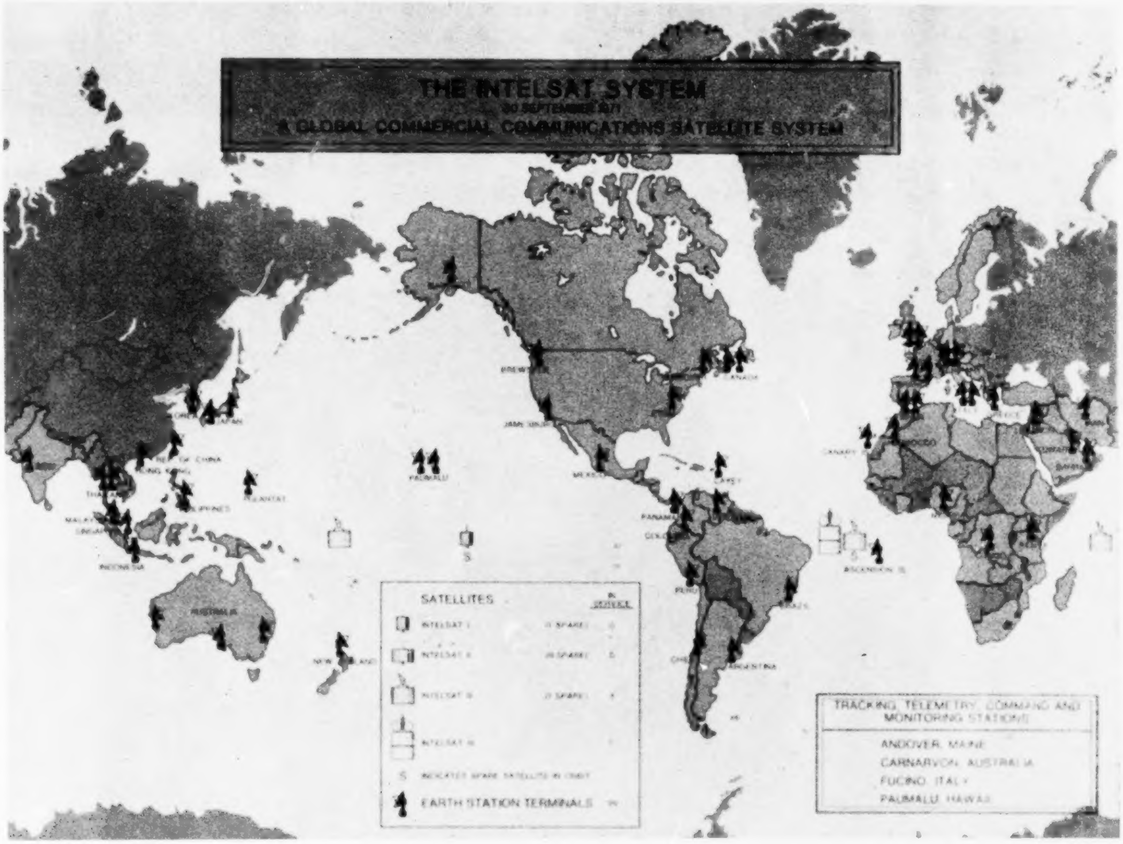

THE INTELSAT SYSTEM
30 SEPTEMBER 1971
A GLOBAL COMMERCIAL COMMUNICATIONS SATELLITE SYSTEM
SATELLITES
IN SERVICE
INTELSAT I
INTELSAT II
INTELSAT III
INTELSAT IV
S INDICATES SPARE SATELLITE IN ORBIT
EARTH STATION TERMINALS
TRACKING, TELEMETRY, COMMAND AND MONITORING STATIONS
ANDOVER, MAINE
CARNARVON, AUSTRALIA
FUCINO, ITALY
PAUMALU, HAWAII
PAUMALU
AUSTRALIA
INDONESIA
PANAMA
PERU
BRAZIL
ARGENTINA
ASCENSION IS.
CANARY IS.
MEXICO
CANADA
S
S

Figure 9. The INTELSAT System.

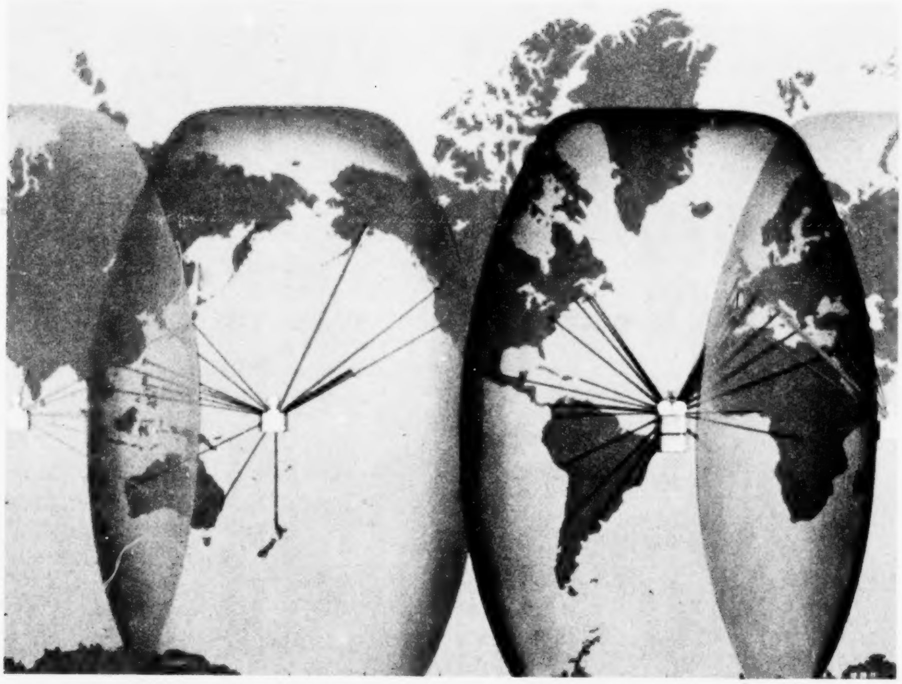
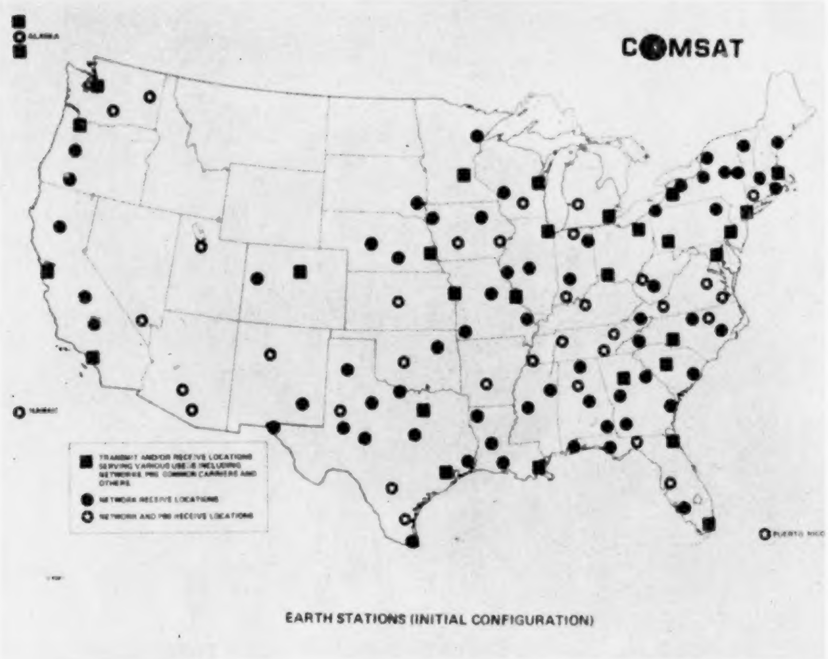
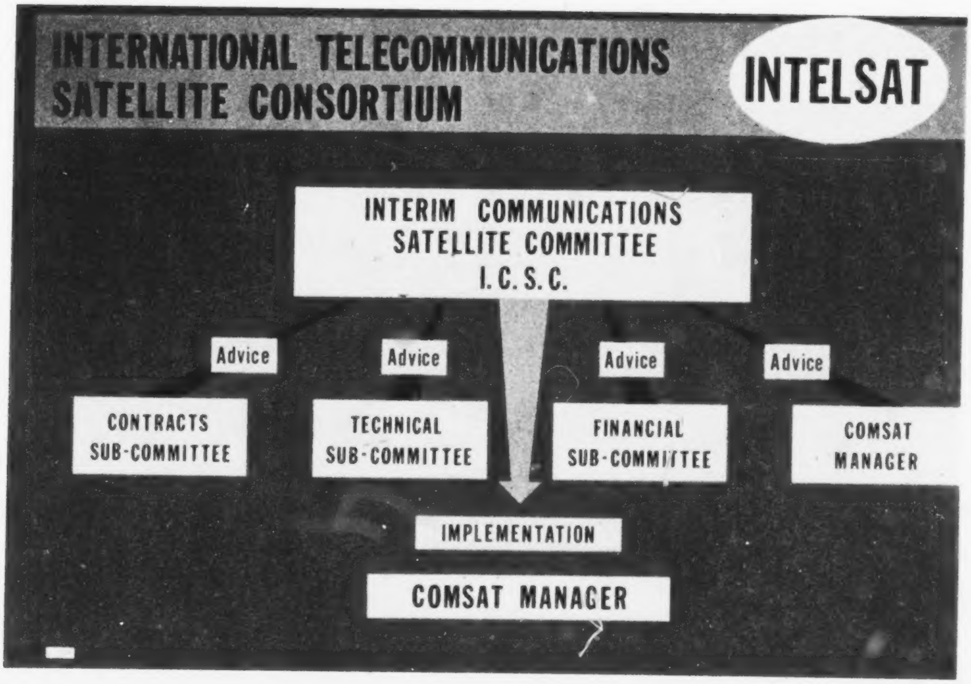


Figure 10. INTELSAT System satellite paths and coverage by region.



COMSAT
ALASKA
HAWAII
PUERTO RICO
TRANSMIT AND/OR RECEIVE LOCATIONS SERVING VARIOUS USERS INCLUDING NETWORKS PBS COMMON CARRIERS AND OTHERS
NETWORK RECEIVE LOCATIONS
NETWORK AND PBS RECEIVE LOCATIONS
EARTH STATIONS (INITIAL CONFIGURATION)

Figure 11. U.S. earth stations (on topographical map with U.S. borders).



INTERNATIONAL TELECOMMUNICATIONS SATELLITE CONSORTIUM

INTELSAT

INTERIM COMMUNICATIONS SATELLITE COMMITTEE I.C.S.C.

Advice

Advice

Advice

Advice

CONTRACTS SUB-COMMITTEE

TECHNICAL SUB-COMMITTEE

FINANCIAL SUB-COMMITTEE

COMSAT MANAGER

IMPLEMENTATION

COMSAT MANAGER

Figure 12. Organization of INTELSAT.

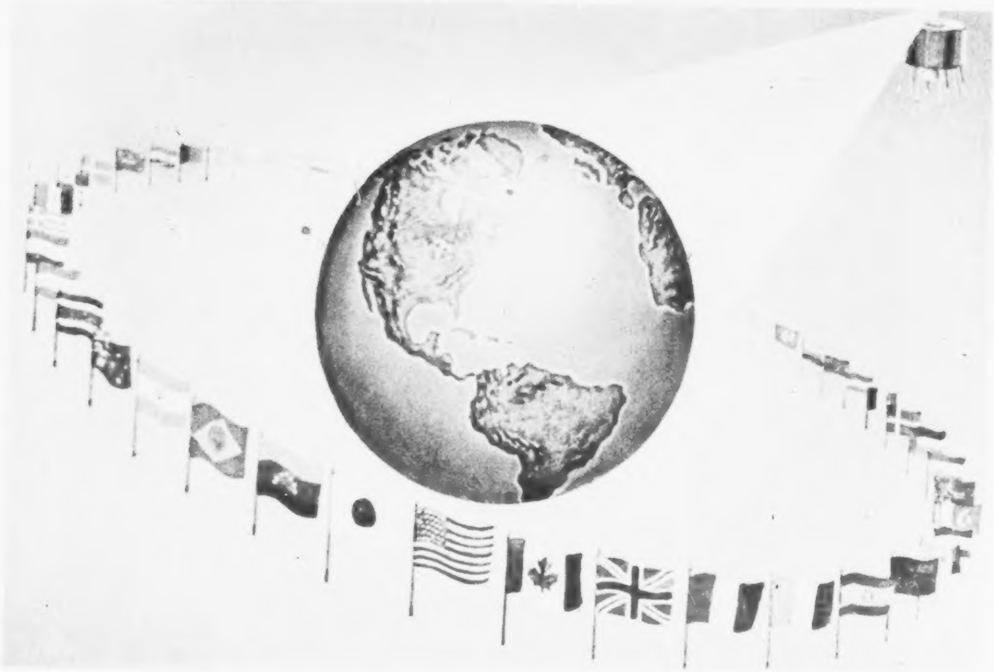


Figure 13. Flags of INTELSAT member nations.

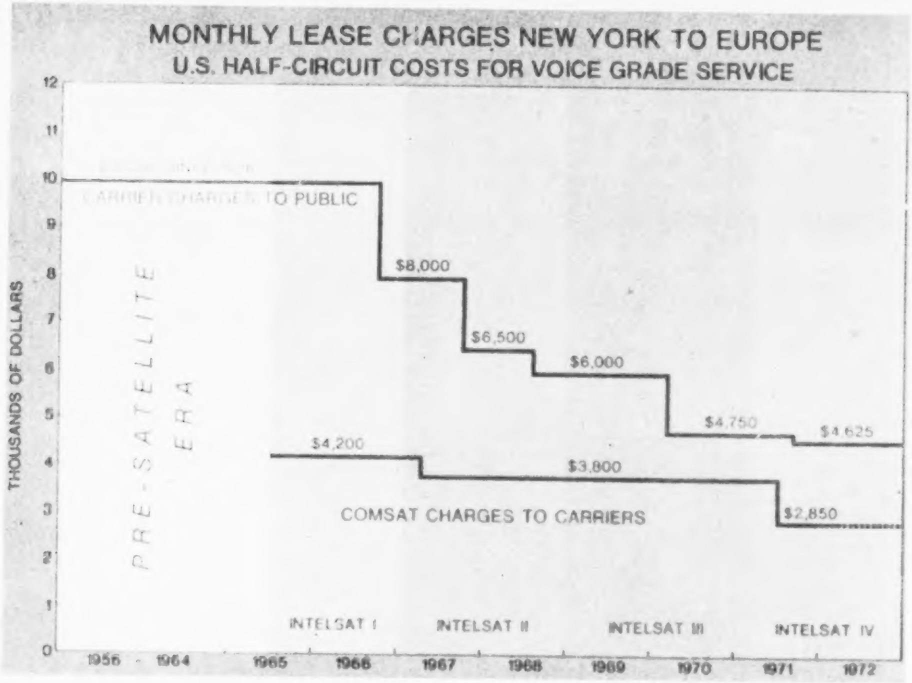


Figure 14. Monthly lease charges (New York to Europe).

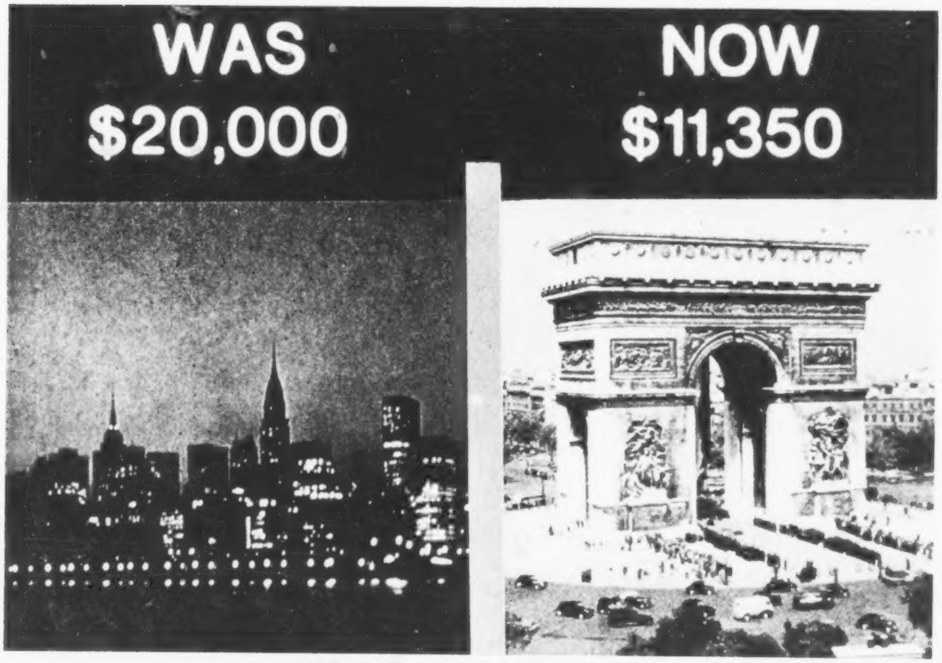

WAS
$20,000
NOW
$11,350

Figure 15. Circuit costs (New York to Paris).

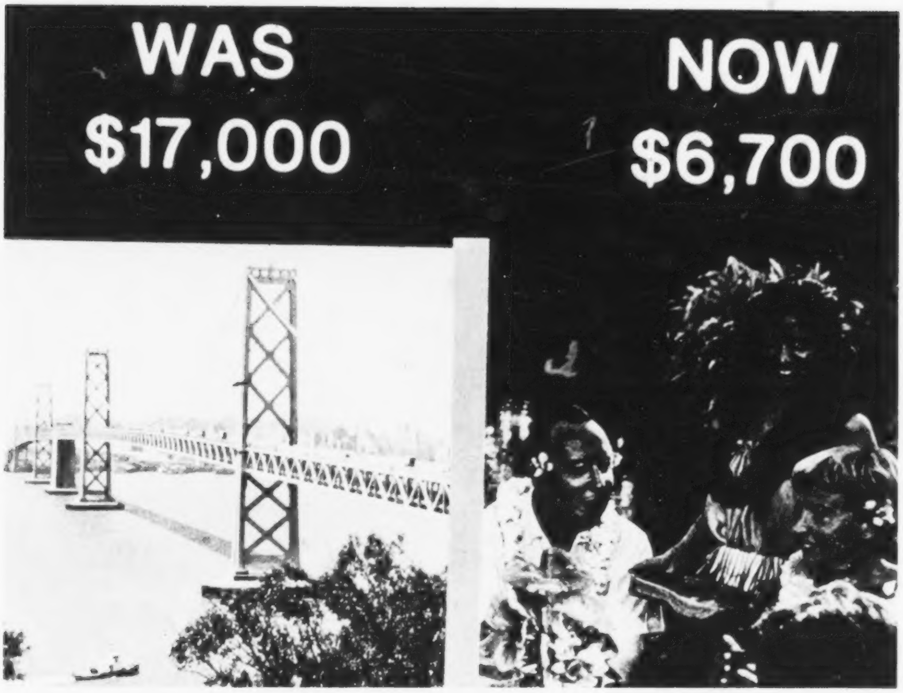

WAS
$17,000
NOW
$6,700

Figure 16. Circuit costs (San Francisco to Honolulu).

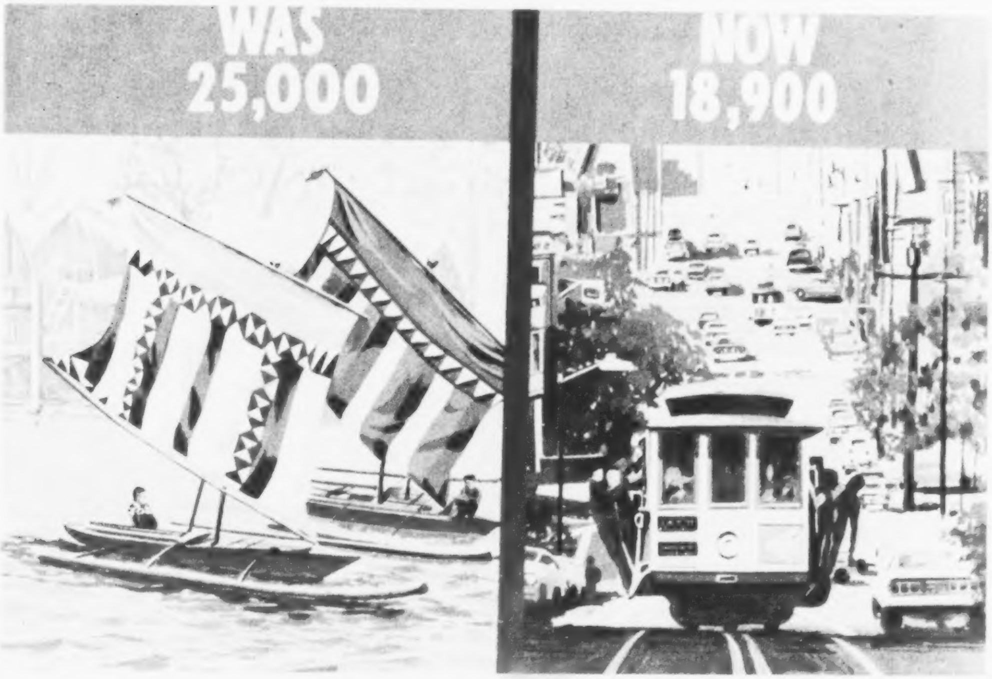

WAS
25,000
NOW
18,900

Figure 17. Circuit costs (San Francisco to Philippines).

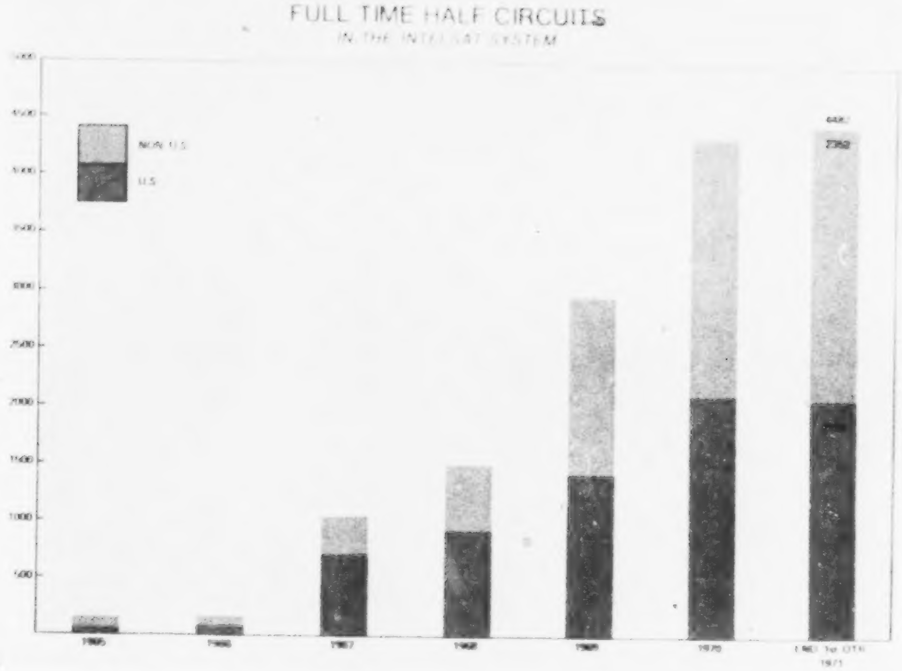


Figure 18. Full-time half-circuits in the INTELSAT System.

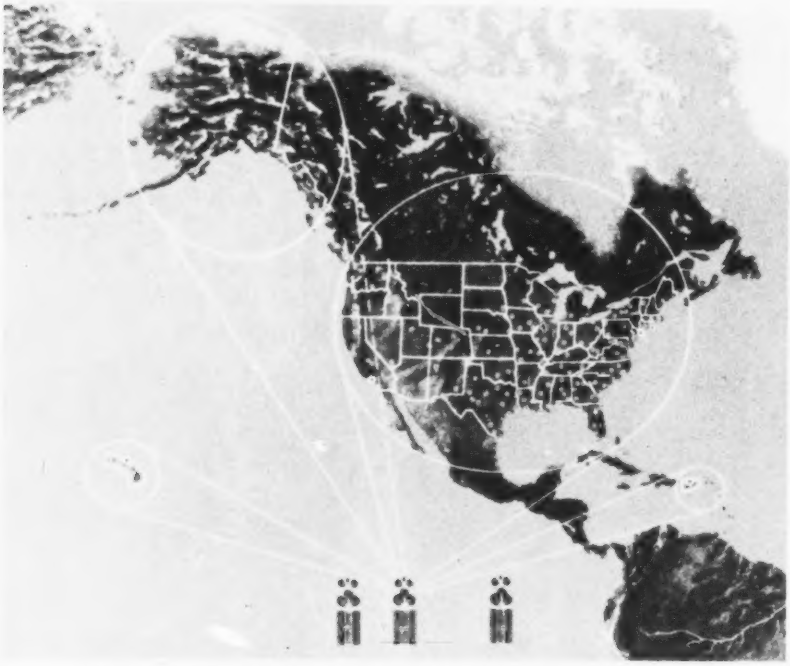


Figure 19. Multipurpose Domestic System II map.

Figure 20. Domestic earth stations (initial configuration).

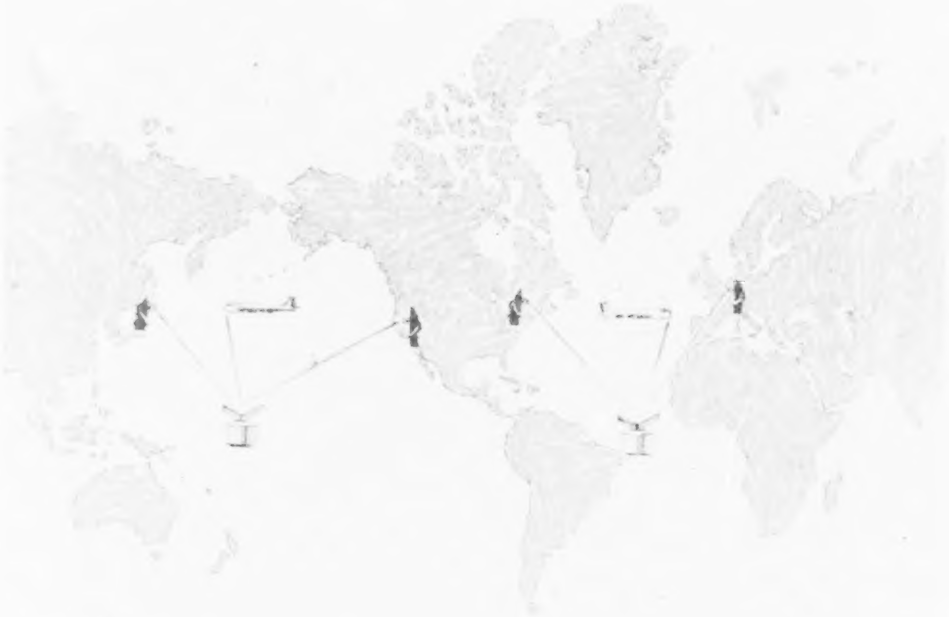


Figure 21. Aeronautical satellite services.

Figure 22. New dimensions, earth from the moon.

# DEVELOPMENT AND APPLICATION OF COLOR TELEVISON FOR APOLLO XV AND BEYOND

By Samuel Russell
RCA Astro-Electronics Division
Princeton, New Jersey

Television played a major role in the spectacular success of Apollo XV. From a research viewpoint, the quality of the video enhanced the value of the lunar surface observations. The real-time transmission of astronaut activity on the lunar traverses undoubtedly increased the popular appeal of the overall mission, also. What was actually done to develop and improve the quality of the television system used on the Apollo XV mission? In this paper, I would like to describe briefly the television system developed for the mission, identify the factors contributing to the high quality of the pictures generated on the lunar surface, and explore several possible present and future uses of the television equipment developed for Apollo XV.

Four factors contributed to the success of Apollo XV television. The first factor was mobility. The television camera accompanied the astronauts during their explorations of the lunar surface and permitted television coverage from a variety of locations on the moon. Remote control of the camera system from earth also was an important factor in the success of the mission. Now the camera could follow the action and zoom-in on details of the lunar surface! A third factor consisted of improvements in television camera performance. The "smears" and "blurs" seen on television during previous missions were eliminated. Gone also were the "Casper the ghost" images of the astronauts. But the new television camera alone was not the only technical improvement in the system.

The fourth and final factor contributing to the high quality of Apollo XV television was a major improvement in the overall television transmission system - mainly on earth. The original network of ground equipment used for the manned space program at NASA was not designed to receive and process color television signals for network distribution. Therefore, a joint NASA and RCA effort was organized to review and improve the entire television transmission system — from the lunar surface to the home receiver. The objective was to generate a television picture from the moon that was just as good as the pictures received of the local Saturday afternoon ballgame! A great deal of work was required to achieve this objective.

Considering the above factors in more detail, Figure 1 shows the components of the television system mounted on the Lunar Roving Vehicle (LRV). On the left-hand side is the completely self-contained color camera unit (CTV). During the lunar landing, the camera was mounted on the Lunar Module (LM) Falcon, in a position that could view the astronauts descending the steps. The camera then was mounted on a tripod to view deployment of the LRV from the LM. After deployment of the Rover, the camera was transferred to the television control unit (TCU) mounted on the vehicle. The television control unit decoded the radio commands from earth and performed the functions shown in Figure 1. The control unit also positioned the camera left or right and up or down in response to remote commands from earth.

The Lunar Communications Relay Unit (LCRU) is shown at the bottom of Figure 1. This unit contained the television transmitter and other communication equipment required for relaying voice and other signals between the backpacks carried by the astronauts and earth. The high-gain antenna beamed the television signal to earth. The camera (CTV), control unit (TCU), relay unit (LCRU), and antenna together were, in reality, a complete television station. The television shown in Figure 2 (taken by the equipment at Cape Kennedy 1 month prior to the mission) is mounted right on the front bumper of the Rover! When the astronauts stopped on the lunar surface, one of them got off, turned a power switch ON, aimed the antenna at earth, and the show began!

Figure 3 shows the color camera (CTV) and the remote control unit (TCU). The camera functions that can be operated by ground command are shown. The camera may be panned to the left or right, or tilted up and down. Motorized drives in the lens assembly allow changes in the lens focal length and aperture. Exposure control and power also may be controlled from earth. The ground controller at MSC-Houston has a set of 18 pushbuttons with which he can control all camera operations (Fig. 4). If the controller wanted the camera to pan left, he first depressed the PAN LEFT button, and the camera moved slowly to the left. The camera motion continued until he depressed the PAN STOP button.

The flight controllers at Houston faced a unique time delay problem. When a pushbutton was pressed, 3.5 sec passed before any response was seen on the television screen. Only through realistic simulation of the time delay before the mission were the controllers able to train themselves to follow the action.

In discussing the improvements in the Apollo XV camera, the difficulty in obtaining good television pictures on the moon must be stressed. Lighting on the moon consists of extreme contrasts. The astronauts appear brilliant because of the highly reflective cloth of the spacesuits. The lunar soil itself, however, is rather dark. Furthermore, shadows on the moon are extremely dark because no sky light exists to soften the shadows. One way to solve the lunar illumination problems was to develop a compatible camera tube. A tube under development at RCA, known as a Silicon Intensifier Target (SIT) tube, was found to have the characteristics needed for the Apollo XV camera. The tube is very sensitive and can see details in shadow areas. It also can withstand the direct rays of the sun without being damaged. Sensitivity of the SIT tube can be controlled electrically over a range of light levels of about 1000 to 1.

In conjunction with the SIT tube, all circuitry in the camera was of such a nature as to optimize performance under conditions expected on the moon. Figure 5, a good example of this optimization, shows the camera is imaging two astronauts on a scale model of the lunar surface. One of the astronauts is in direct sunlight (simulated) while the other is in shadow. The television system just does not have the dynamic range to simultaneously image properly both the astronaut in sunlight and the one in shadow. This problem may be resolved, however, by having two separate modes of automatic light control (ALC). A peak mode detects the brightest object in the scene, and adjusts the SIT tube sensitivity to give the highest modulation value of the picture signal for this object. In this way, a good image of the astronauts is obtained. An average mode is used for looking in the shadow, and picture highlights are allowed to saturate and "bloom." A brightly lit astronaut cannot be seen clearly in an average mode because his image has saturated. The astronaut in shadow, however, can be seen clearly. By using two modes of ALC, improved exposure control for the pictures seen during Apollo XV was possible.

When the Apollo XV television signal left the transmitter and antenna on the moon, the signal traveled to one of three ground stations on earth. Let us use, for example, the Australian station and trace the path of the television signal from there to a home television receiver. From the Australian ground station, the signal went via a groundline to a COMSAT ground station. From the COMSAT ground station, the signal was transmitted to INTELSAT, a satellite 22 000 miles above the Pacific, then back to a COMSAT ground station in California. Bell System then took the signal to MSC-Houston where the color television signal was changed to the form used for commercial color television transmissions. Finally, the signal was distributed to the television networks from MSC-Houston for transmission to the public. Along this complicated transmission path from the moon, potential system problems are constantly threatening television signal quality. The NASA and RCA systems team turned up quite a number of problems that could have caused picture degradation. In one case, the ground station receivers caused a breakup in the edge of the picture. In another case, a special processing amplifier was introducing noise. A filter, designed to separate the voice signal from the television signal, was producing ghosts in the picture. These and other problems were discovered and, for the most part, were fixed for the Apollo XV mission.

Another difficult task was isolating the location of ground system malfunctions during television transmissions. In commercial network operations in the U.S., the originating station gives the television signal to a common carrier (i.e., the Bell System) which then routes the signal to its destination. For the Apollo mission, however, many carriers were involved. There was one link from the moon to the earth, another link through a common carrier in Australia under the jurisdiction of the Australian Postal Department, then another through COMSAT and International Telecommunication Satellite Consortium (INTELSAT) over the Pacific, and finally one through the Bell System to the space center. A break in any one link would have spoiled the show. To pinpoint where problems were occurring was a difficult task. For this reason, a special NASA Television Flight Control Group was formed to supervise the entire television operation during the mission. The manager of this group was located in the control center right behind the controller operating the camera. From this vantage point, he could communicate with points all over the world and locate problems as they occurred. Fortunately, no serious problems occurred, and the show went off on schedule.

What sort of applications can the Apollo XV television system be used for? In science, there are a number of advantages in having high-quality television. One is just having a good record of scientific exploration. During the Apollo XV, the television signals provided invaluable documentation of the lunar surface investigations. This was really unexpected by scientists and the scientists realized the value in these analyses only after extensive replay of the videotapes. A film record of the same data would not have been practical because the weight of film would have reduced the weight allotment for lunar samples. Thus, television provided the ideal way to secure these data.

Television also may change the method of doing scientific research in two rather interesting ways. The use of high-quality television for costly scientific projects such as lunar exploration permits "real-time" scientific research. When a scientist wants to make a normal geological exploration of a region, he first researches the area, then plans an exploration, and goes into the field to take samples. Then he analyzes his field data and defines a geological model. Generally, his conclusions lead to the need for more additional field work and a new model. On earth, this iterative process for scientific research is acceptable.

In exploring the moon, however, the high cost involved precludes such luxury. Returning to the same place to gather data for an incomplete model is not feasible. Instead, the whole investigative procedure must be compressed within the available mission time. Scientific teams must work in real time to analyze data and decide how to proceed with the exploration as the exploration is taking place.

Television, for example, could have been used to an advantage during the Apollo XIV mission when the astronauts were on their second extravehicular activity (EVA) near the edge of Cone Crater. They reported seeing some white-rock formations, but did not elaborate. The response from Houston was for them to take a photograph of a sample of the white rock. When the films were developed after the mission, the photograph of the white rocks showed something completely unexpected. Never had formations like this been seen on the lunar surface nor have they been seen since. Due to the pressure of time, or perhaps limited geological training, the astronauts missed the significance of these formations. Scientists on earth may have seen the formations with television. The EVA timeline then would have been reorganized to sample this region more fully in an attempt to explain these formations.

A second use of the television camera during future Apollo missions is as a multispectral sensor. The SIT pickup tube has a broader spectral response than the human eye, and the moon exhibits much higher contrast in the infrared spectral region than in the visible region. A television camera, therefore, can enable scientists on earth to see scene details that even the astronauts themselves cannot see.

Television also is important as a tool to educate and to give everyone a unique sense of participation in the Apollo missions. The many applications of space technology to our more earthly needs must be realized by the public, especially in the fields of communications, weather forecasting, navigation, and earth resources surveying. The space program is really beginning to bear fruit, and yet many exploratory parts of the space program are difficult to justify to the American public. For the Apollo missions, the justification is science. Much stress has been placed on the importance of discovering how the moon was formed, what relationships it has with earth, and how the moon may hold the secrets to the origin of the solar system.

To the man on the street, the "need to know" is often a little difficult to understand. He probably has justified to himself why we are exploring space, the moon, and the planets - just as a mountain climber has reasons to climb a mountain. By allowing him to see and experience space exploration through television, as we did on Apollo XV, perhaps we have the key for his continuing support of our endeavors in space.

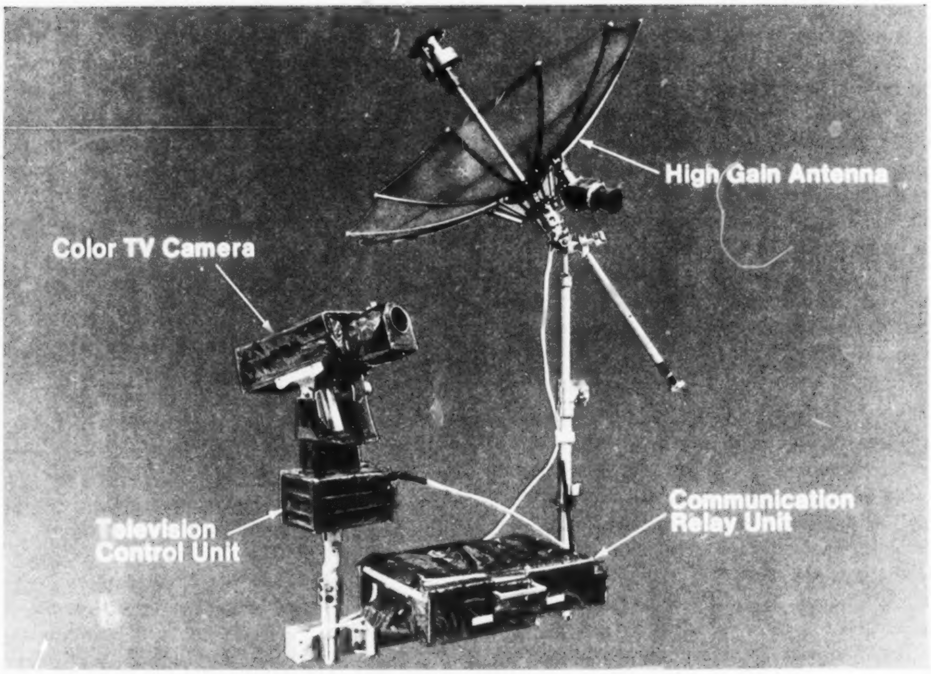

High Gain Antenna
Color TV Camera
Communication Relay Unit
Television Control Unit

Figure 1. Lunar Communication/Television System

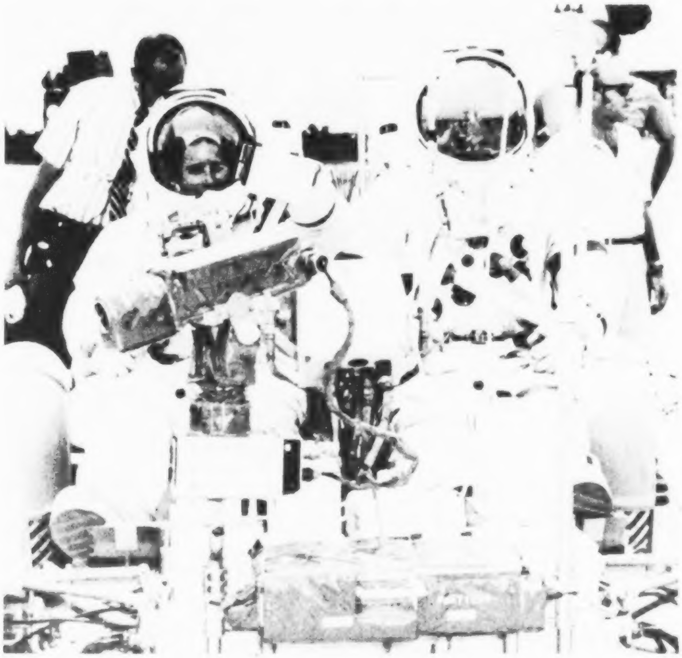


Figure 2. Television installation on Rover.

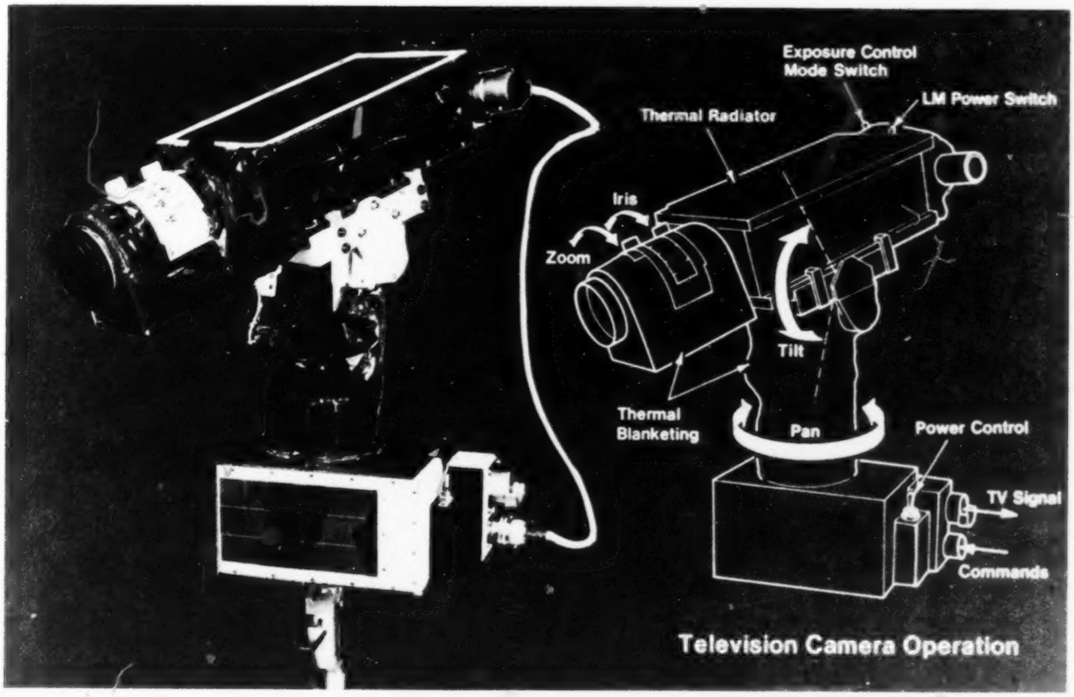
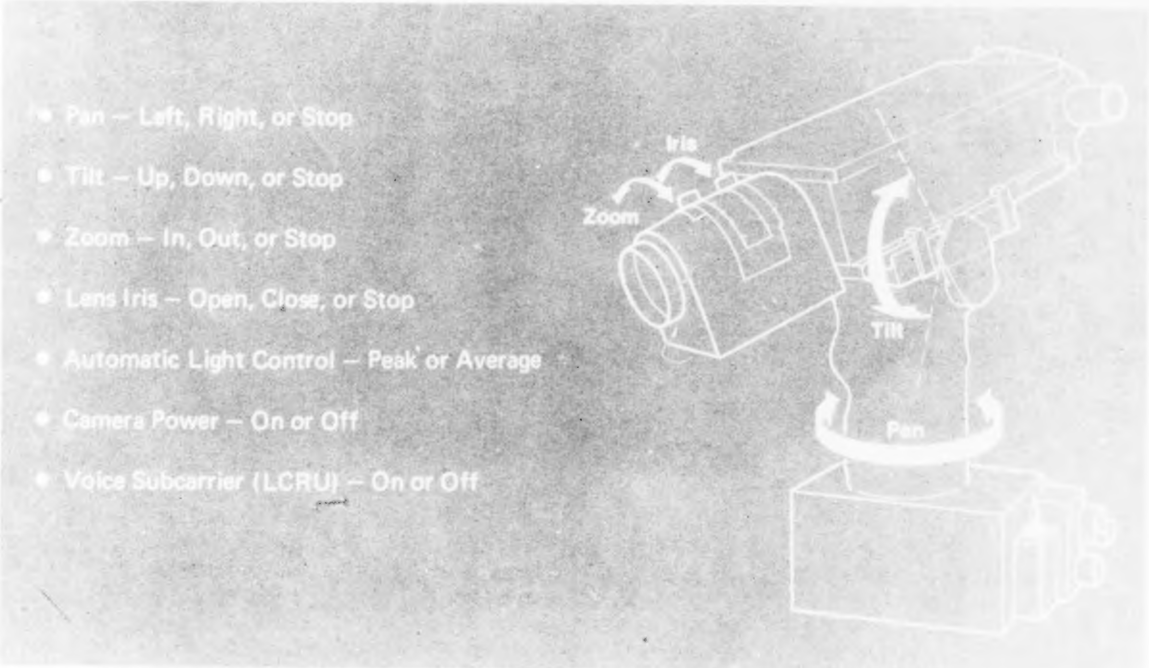

Exposure Control Mode Switch
LM Power Switch
Thermal Radiator
Iris
Zoom
Tilt
Thermal Blanketing
Pan
Power Control
TV Signal
Commands
Television Camera Operation

Figure 3. Ground Commanded Television Assembly (GCTA).


- Pan – Left, Right, or Stop
- Tilt – Up, Down, or Stop
- Zoom – In, Out, or Stop
- Lens Iris – Open, Close, or Stop
- Automatic Light Control – Peak or Average
- Camera Power – On or Off
- Voice Subcarrier (LCRU) – On or Off

Iris
Zoom
Tilt
Pan

Figure 4. Command functions.

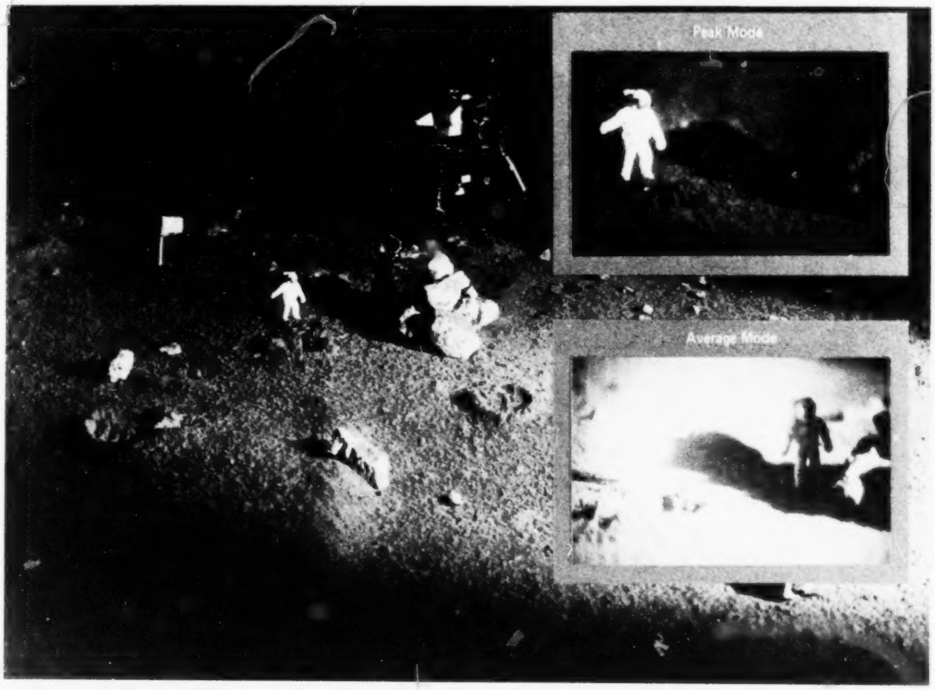

Peak Mode
Average Mode

Figure 5. Automatic light control.

# SESSION VI
# MEANING OF SPACE TO THE NATURAL SCIENCES

# ADVANCES IN HIGH ENERGY ASTRONOMY FROM SPACE

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Senior Vice President
American Science and Engineering

## INTRODUCTION

In the life of the modern city it is rare for us today to turn our sight to the night sky and contemplate the stars. A thousand physical and emotional stimuli prevent us from doing it; thus, in the age of space travel, the stars seem to have receded farther away from our consciousness than in the past. The question is often asked: why X-ray astronomy, or astronomy in general?

For our remote ancestors the contemplation of the heavens was an important part of life. From the practical point of view, the orderly movement of the celestial bodies was used to regulate the time for sowing, for the harvest, for the hunt, and then for market. The position of the stars was used as the only compass for the traveler on land and on sea. Later, the study of the orderly and cyclical nature of the heavenly notions became interwoven with myth, legend, and religion. When today's astronomer looks back to his colleagues of the past, he does not find men like himself, with the same outlook on life and from the same backgrounds, but rather poets, philosophers, priests, and princes with intellects quite as powerful as our own, who had realized several thousand years ago a powerful synthesis of their cosmological views and the life of their society.

In the stupendous accomplishments of these predecessors, such as the construction of the astronomical observatory of Stonehenge, and possibly the understanding of the precession of the equinox, which implied the oral transmission and knowledge of cyclic phenomena with periods of hundreds and thousands of years, we encounter an interest and desire for pure knowledge, with no possible practical application. This has made astronomy the intellectual adventure it has remained to this day.

While the study of the universe by means of astronomical observations has traditionally played a large role in the advances of knowledge of the physical sciences, its central impact and appeal have been in the deeper knowledge man obtains of himself by studying the universe in which he lives. The cultural and social impacts of the Copernican, Keplerian, and Newtonian revolutions are only now beginning to be fully realized. Primarily because of the development of new techniques for exploring regions of the electromagnetic spectrum outside the optical window, a spectacular series of discoveries has occurred in the past two decades. These were so surprising and enigmatic that they provided a powerful stimulus for further exploration and forced a reappraisal of astrophysical theories.

First, through radio astronomy, came the realization that explosive phenomena in stars (supernovae) released tremendous amounts of energy, a large fraction of which appears in the form of high-energy particles. Then followed the discovery of radio galaxies and quasars, leading to the conclusion that explosive phenomena are taking place on a very large scale in galaxies as a whole. The recent discoveries of the microwave background radiation, X-ray sources, and pulsars have strengthened the conclusion that in our universe high-energy processes (i.e., processes in which the energy released per gram is much greater than for normal stellar matter, ~1 erg/gm-sec) play a major and quite possibly a decisive role. The study of these processes defines a new field, high-energy astrophysics, the central problem of which is an understanding of the source of the tremendous amounts of energy released in X-ray sources, supernovae, radio galaxies, quasars, etc., and the processes by which the high-energy particles responsible for the radiation from these objects are produced. It is no overstatement to say that the resolution of these problems constitutes one of the most important and fascinating tasks in all of physics.

Since the production of high-energy photons is to be expected whenever high-energy particles collide with a magnetic or photon or particle field, and whenever high temperature plasmas are present, it is not surprising that X-ray astronomy has made significant contribution to the development of the field of high-energy astrophysics, despite the fact that the total amount of observing time has been small compared to that in other fields. We can expect this contribution to be much greater in the future, when increased observing time becomes available, because a number of crucial observations can be made only in the X-ray band.

Since high-energy photons from a few electron volts to several million electron volts do not penetrate the earth's atmosphere, observations in this energy range became possible only by the development of balloons, rockets, and satellites (Fig. 1). This development made it possible for the first time in man's history to observe the sky unimpeded by the atmospheric blanket that surrounds us on earth. While this opportunity was of some importance in improving "seeing" conditions for traditional observational techniques, its true significance was in permitting the observation of regions of the spectrum for which the atmosphere is an opaque barrier. In one stroke, space astronomy could extend the range of observable wavelengths by as many decades as had been until then available.

In retrospect, it is easy to understand why X-ray observations, rather than ultraviolet or gamma rays, should have provided us the first major surprises in space astronomy. First, the existence of a diffuse interstellar gas produces a sharp increase in absorption at 13.5 eV, the energy corresponding to the ionization potential of atomic hydrogen. While photons from the visible through the ultraviolet up to this energy can traverse the interstellar medium relatively unattenuated, photons with energy greater than 13.5 eV are completely absorbed over extremely short distances, in astronomical terms. The interstellar medium does not again become transparent until we reach energies of a few hundred electron volts in the X-ray range. On the low-energy side of this barrier, the processes we can observe are mainly the same ones that give rise to the visible light spectrum we observe. It is only on the high-energy side of the barrier that the photons we observe may carry information about vastly different physical processes and states of matter (Fig. 2). Photons in the X-ray range of energy are the lowest energy and, therefore, the most abundant photons beyond this barrier that can penetrate galactic distances. Thus, it is not surprising that the first discoveries in high-energy astronomy occurred in the X-ray rather than in the gamma-ray range of energy.

In the short 8 years since the first detection of cosmic X-ray sources, a number of significant observations have been made which have revealed to us a different aspect of the cosmos. We have discovered the existence of a class of stellar objects whose main mechanism of electromagnetic energy loss is through emission of high-energy photons. A well-known example is Sco X-1, the first of the cosmic X-ray sources to be detected. The name "extar" which was proposed for this object finds some justification in the fact that while in main sequence, stars emission in the visible light range of wavelengths exceeds, by orders of magnitude, the emission in X-rays. In Sco X-1 this ratio is reversed.

The pulsar in the Crab Nebula, which has been first detected through its radio pulsations, has been also shown to emit most of its radiative energy in the X-rays' range of wavelengths. Also, its rotational energy which is believed to be expended in accelerating particles to relativistic energy may ultimately be dissipated by energy loss of the electrons through synchrotron emission, mainly in the X-ray range of wavelengths. We have observed X-ray emission from exploding galaxies, such as M-87, where again the energy emitted in X-rays equals or exceeds all other forms of radiative dissipation. We have perhaps detected the emission from intergalactic gases, whose existence and density play an essential role in determining closure or openness of our universe. The existence of these gases can only be detected through their X-ray emission if they are as hot as presently believed.

A general discussion which pretends to encompass all X-ray astronomy would be as hopeless a task today as would be the case for optical astronomy. The sheer richness and variety of the field prevents completeness. I will, therefore, endeavor only to mention briefly the observational techniques and then to give an example of what we learn through X-ray observations of a few objects, such as the sun, a stellar object, and a galactic object, followed by a few comments about what we can expect from future developments.

## Instrumentation

The essential elements of an X-ray experiment are a detection device, such as photon counter or film, and a collimating device to define the direction from which the X-rays are coming. These units must be rigidly mounted on a carrier (rocket or satellite), and some means must be provided to maneuver or point the carrier in order to acquire or sweep interesting regions in the sky. Some means to determine instantaneous celestial coordinates for the instrumentation must be provided. Finally, there is the problem of signal conditioning and return of the data to the ground.

Rather than discussing in detail each element of instrumentation, I will mention two examples of complete instrument systems presently in use.

Uhuru is the first satellite entirely devoted to X-ray astronomy (Fig. 3). It was launched in an equatorial orbit of 500 km from Kenya, Africa, on December 12, 1970. This day is the anniversary of Kenyan independence, hence the Swahili name for freedom, Uhuru. Data are stored onboard on a tape recorder during a 9-min period and then transmitted to the ground when the satellite passes over a ground station at Quito, Ecuador.

The satellite's fields of view and scanning mode are shown in Figures 4 and 5. As the satellite slowly rotates about its axis, the detectors scan a band in the sky 5 deg wide and 360 deg long. By magnetic torquing against the earth's magnetic field, we can change the orientation of the spin axis and thus observe any desired part of the sky. A typical sample of data is shown in Figure 6.

This satellite is the most sensitive X-ray instrument yet at our disposal. The relatively large area of detection, 1 ft$^2$, and, most important, the long time of observation available, make it some 10 000 times more sensitive to weak extrasolar X-ray sources than the crude rocket experiment, with which the first X-ray star was discovered in 1962. Most of the data I will discuss today come from this satellite.

A totally different system which up to now has only been used for solar X-ray studies is shown in Figure 7. It is mentioned here both to introduce the observations of the sun in X-rays (which I will discuss briefly), and because of its importance for stellar X-ray astronomy in the future. The system consists of an X-ray grazing incidence mirror which forms a high-quality real image in the focal plane. The mirror consists of a highly polished glass or metal surface on which X-rays impinge at very small angles of grazing incidence, about 1 deg. Under these conditions, X-rays of a few tenths to a few kilovolts reflect with efficiencies of the order of 1.

The X-rays undergo two reflections from a paraboloid and a hyperboloid of resolution (Fig. 8), and the image formed at the focus is then recorded on film or on a television camera. Images with angular resolutions of a few arc seconds, comparable to the ones achieved in visible light, can be obtained for intense sources, such as our own sun, during exposures of a few seconds. Thus, a rocket flight of only 300 sec provides the opportunity of obtaining several photographs of the sun during one flight. The flux of X-rays from the sun is of about $10^5$ photons/cm$^2$ sec. Even the nearest and most powerful stars are so distant that the X-ray flux reaching us at earth is many orders of magnitude smaller, so that the much longer observation times provided by satellites and much larger telescopes of this type will be needed before the technique can be applied to extrasolar sources.

## The Sun as an X-ray Star

X-ray emission from the quiet sun originates in the upper chromosphere and corona. Low density and high-temperature plasmas are created in these regions by heating from sound or hydromagnetic waves originating from below the atmosphere. The details of this heating mechanism whereby a million-degree temperature region is created surrounding the very cool surface of the sun (a few thousand degrees) are not fully understood. Independent of their origin, the thin ($10^{10}$ particles per cm$^3$) and hot ($T > 10^6$ °K) gases thus created become almost completely ionized. Emission in X-rays can occur as free-free collision between particles (thermal bremsstrahlung continuum), as free bound (recombination continuum), or line emission. Most of the emission from the quiet corona takes place at temperatures of the order of 1 or 2 million degrees and, therefore, appears mainly as line emission. During flares or from active regions the temperature can reach two or three times that value. The hot plasmas which generate the observed X-rays are contained by the sun's magnetic field. Thus, we would expect to observe X-ray structures reflecting the configuration of the coronal magnetic field. This is precisely what one observes, as shown in Figure 9 (obtained with a grazing incidence telescope during a rocket flight on March 7, 1970, shortly after the solar eclipse).

The striking feature of Figure 9 is the absence of the solar disk, much too cold to be observed in X-rays, and the appearance of a complex and varied structure reflecting the presence of plasmas and the configuration of the magnetic field. Tubular arches and loops of enhanced density and temperature rise to heights of more than $10^5$ km above the photosphere. X-ray observations are thus two-dimensional projections of these structures.

Rather than discussing in detail the significance of the various small- and large-scale structures, I would like to conclude this discussion of the X-ray sun by quoting some energetics. The sun emits about $4 \times 10^{33}$ ergs/sec in all wavelengths. In X-rays, its luminosity is only of about $10^{25}$ to $10^{26}$ erg/sec. Thus, at the most, one-millionth of the sun's total energy is emitted as X-rays. We will see in what follows that although this ratio is fortunate for us, it is by no means true for every stellar object. In fact, if all stars emitted at the same rate as our own sun, we could not have discovered their existence. We will see that stars exist in which the central object emits a negligible amount of the total energy dissipated by electromagnetic radiation; its importance is to provide, by nuclear burning or release of rotational or gravitational energy, the energy that is expended in the radiative process and to serve as an anchor to gravitationally or magnetically contain the plasmas or high-energy particles that emit the bulk of the radiation.

## Extrasolar Sources

The X-ray Sky. When we analyze the information that Uhuru is sending us about the night sky, we observe the following main features:

1. Many stellar objects, now 80 or so, are observed to emit copious amounts of X-rays. They appear to be strung throughout the disk of our galaxies at great distances from us (Fig. 10). They emit most of the radiation in X-rays (typically $L_x/L_v = 1000$) and they are among the most powerful emitters in the galaxy at $10^{36}$ to $10^{38}$ erg/sec, some $10^3$ to $10^5$ times our own sun.

2. These X-ray sources appear to be associated with a variety of stellar objects, such as:

a. Identified

- Supernova remnants Type I - Crab, Tycho
- Supernova remnants Type II - Cas A
- Pulsar - NP-5032
- Blue varying star - Sco X-1, Cyg X-2

b. Not identified

- Pulsating white dwarfs - Cen X-3 ?
- Neutron stars - 340 + 0 ?
- Black holes - Cyg X-1 ?

3. There exists a large number (40) of extragalactic sources of which about 12 have been identified. They include:

| | |
|---|---|
| a. Galaxies of our own | LMC |
| b. Local cluster (50-100 kpc) | SMC |
| c. Radio galaxies (10 Mpc) | M87, NGC 5128 |
| d. Seyfert galaxies (10-70 Mpc) | NGC 1275<br>NGC 4151 |
| e. Clusters of galaxies (100 Mp) | Coma Cluster |
| f. QSO (600 Mpc) | 3C273 |

The intrinsic luminosity of these objects ranges from about $10^{39}$ erg/sec for LMC to about $10^{46}$ erg/sec for 3C273.

4. A diffused intense background, partly originating in our own galaxy and partly outside, possibly at cosmological distances from us, is observed. This background could be due to a number of unresolved discrete weak sources or to emission by gas or particles in interstellar or intergalactic space.

I would like to give two examples of study in stellar and galactic astronomy to illustrate the detailed nature of these observations and their significance.

Cen X-3. Cen X-3 is not one of the most intense sources. Its intensity at earth is of about $10^{-1}$ photons/cm$^2$ sec or some 500 times less than the strongest known X-ray source, Sco X-1. It is, however, an extremely interesting source due to its variability, pulsations, and level of detail in which we can study it. It was first observed during rocket experiments exploring the region of Centaurus. It is called Cen X-3 because it was the third X-ray source discovered in this constellation. Uhuru has observed it since January 1971, and is still observing it as of now. Figure 11 shows a plot of the observed intensity of the source in the 2- to 8-keV-energy range during a day. We observe a tremendous change in its intensity occurring in a 1-hr period. This vast change in emitted X-ray energy is a common characteristic of X-ray sources. The time in which such changes occur and the amount of change vary from source to source.

If we observe the emission of this source in more detail, as in Figure 12, we find an even more striking fact. The dotted envelope shows what we would expect to be the response to a constant point source through our instrument as we scan through it. The very large fluctuations we observe, 70 or 80 percent in intensity, occurring during 100 sec are then occurring at the source. The source is thus pulsating in X-rays. If we examine these data in greater detail we find that we can fit them with a sine wave function, including the first and second harmonic. The period is of 4.832 ±0.004 sec. An important question is the stability of the period. If these X-ray pulsations are due to rapid rotation of a stellar object, we would expect them to be maintained for a long time. When we examine this question in detail (Fig. 13), we find that relatively large changes of the period occur in short times of the order of 1 hour. From the rapid change in X-ray emission, we are driven to postulate small regions from which X-ray emission occurs, of the size of earth, or smaller.

Since the source is quite close to the galactic equator, we believe it is quite distant. At 1 kpc its intrinsic luminosity is $10^{36}$ erg/sec. Thus, we have an object one-hundredth the size of the sun, presumably with the same mass, and thus with incredibly high density, emitting some $10^3$ times more energy.

What type of star are we confronted with?

The small radius requires that it be a collapsed star near the endpoint of stellar evolution. Of the three states, white dwarf, neutron stars, and black hole, in which a star is conceived to end, perhaps the white dwarf is more conventional. It turns out that a recent theoretical model, based on a pulsating white dwarf, where a dense atmosphere is heated by shock waves produced by nuclear burning of the shell or accretion, seems to satisfy all observational data. The model makes detailed predictions about the energy spectrum of the source as a function of phase of the pulse (Fig. 14). Detailed comparisons are presently being done to establish the validity of the model. A search is underway to discover a possible optical or radio counterpart to this object. None has as yet been found. One should stress that such violent behavior of white dwarfs had not been understood to take place prior to the observations. In fact, the validity of the model is by no means generally accepted and could be completely destroyed if several other objects of the same type, but shorter period, should be discovered.

A few weeks ago, another object with a period of about 1.3 sec was observed. Shorter periods would strain the white-dwarf hypothesis even further. Many other X-ray sources exhibit pulsations, for instance, the Crab pulsars NP0532 of a 30-msec period, which is interpreted as a rotating neutron star whose gigantic magnetic field dissipates the star's rotational energy by accelerating particles to high energy with consequent emission of X-rays via the synchrotron process.

These observations are so new that they have outrun theory. It is clear, however, that X-rays give us a powerful new tool with which to study the physical processes taking place at the end point of stellar evolution.

## Extragalactic Sources

Leaving now the confines of our own galaxy and the local group, I would like to focus on a recent measurement of X-ray emission from the Coma Cluster of galaxies (Fig. 15). The Coma Cluster at a distance of 90 Mpc, that is some 10 000 times more remote from us than the center of our own galaxy, contains some 800 galaxies emitting a 100- by 100-arc min area of the sky. We find an X-ray source centered very closely to the kinematically determined center of the cluster. If this is not a chance coincidence, which we think we can exclude, the luminosity of the source is $3 \times 10^{44}$ erg/sec, some $10^6$ times the luminosity of our own galaxy. We find that the region of X-ray emission is extended by about 45 arc min and that, contrary to what has occurred for other extragalactic sources, no galaxy with very peculiar optical or radio characteristics coincides with the source location.

We are then led to consider several possible hypotheses:

1. A single galaxy which for some reason (local obscuration) is not conspicuous optically.

2. A large number of individual galaxies in the cluster, too faint to be resolved. This would require galactic luminosity of $10^{41}$ - $10^{42}$ erg/sec which would be in itself peculiar.

3. Last, the source is due to emission via thermal bremsstrahlung from a hot intergalactic gas in the cluster. The data can be fit by a temperature of $70 \times 10^6$ °K with particle velocity of 1000 km $\text{sec}^{-1}$ in agreement with the velocity of the individual galaxies in the cluster.

The mass of the gas would be about $3 \times 10^{13}$ M, which is very large — about 100 galaxies similar to our own, but much too small by a factor of 100 to prevent indefinite expansion of the galaxies in the cluster. In fact, the most significant aspect of this observation was recently pointed out; the amazing fact being not that the emission from the cluster is too large, but that it is too little. If large amounts of intergalactic gas existed, they would have fallen into the cluster and would have been heated to very high temperatures. If one assumes that the mass required to close the universe is in this form, we should have observed an emission of a factor of about 10 times greater from this effect alone.

## Conclusion

I would like to conclude my remarks by mentioning the new observational tools that are planned in X-ray astronomy for the coming decade. With Uhuru, we have achieved angular resolutions of about 0.25 deg, positional accuracies of a few arc minutes, spectral resolution of 10 to 20 percent. In the High Energy Astronomy Observatory Program of NASA, much larger instruments will be made available. The first and second missions, due in 1975, will perform higher sensitivity surveys of the type of instrumentation that Uhuru has pioneered with — similar, though much improved. The third mission will see the first use of a large focusing X-ray telescope from a pointed platform (Fig. 16). This will make it possible to analyze the angular structure and position of sources with resolution comparable to one obtained in visible light. Figures 17 and 18 show the type of improvement one can expect. From this observatory, it will also be possible to analyze in detail the presence of emission lines superimposed on the continuum spectra, to study in great detail the time variations and the polarization of the sources, and to extend the observations to the farthest objects in our universe. It will be possible to study in detail the nature of the X-ray background and perhaps to detect the presence of a hot intergalactic gas, thus contributing to the choice of cosmological models.

While it may yet be too early to completely define the role of X-ray stars and other X-ray emitting objects in stellar and galactic evolution, the wide range of observable phenomena mentioned above and the large energies involved show that the study of X-ray emission is essential to an understanding of the physical processes occurring in many of the objects of greatest astrophysical interest. In addition, the mere notion that high-energy photons could be detected from various extrasolar sources has compelled a rethinking of astrophysical theories.

After a few years of X-ray observations, we have glimpsed a different and important aspect of the universe surrounding us. From the vantage point of this new perspective we have a better understanding of the role and importance of high-energy phenomena in astrophysics. We believe that this new awareness will not be lost in the future. X-ray observations have been an unexpected gift to astronomy from space exploration. So long as space endeavors continue, X-ray astronomy will maintain its rapid rate of progress and take its place beside visible and radio techniques as one of the powerful tools with which to explore the universe.

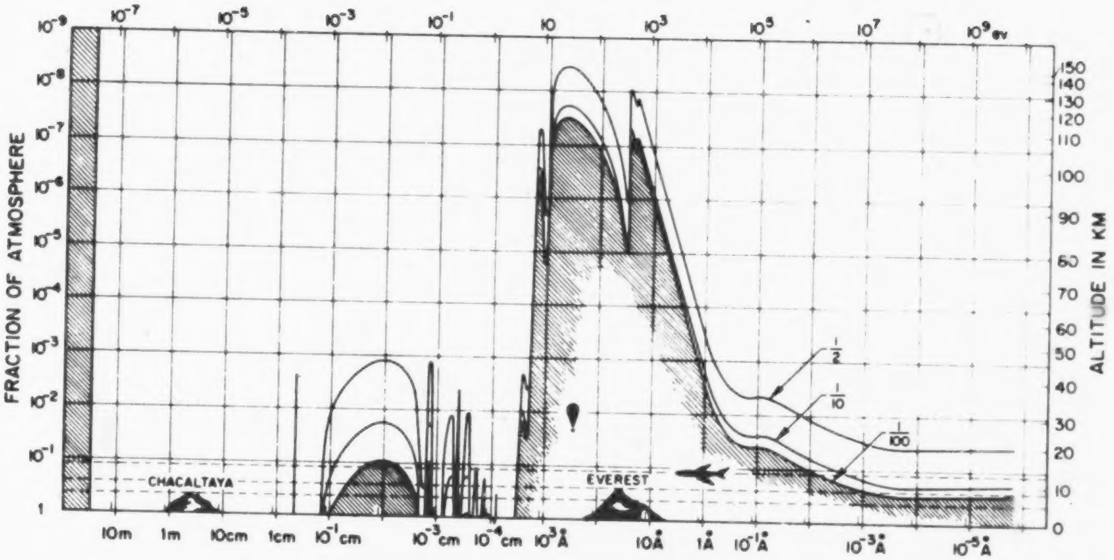


Figure 1. Energy ranges, outside the earth's atmosphere, now observable through balloon, rocket, and satellite development.

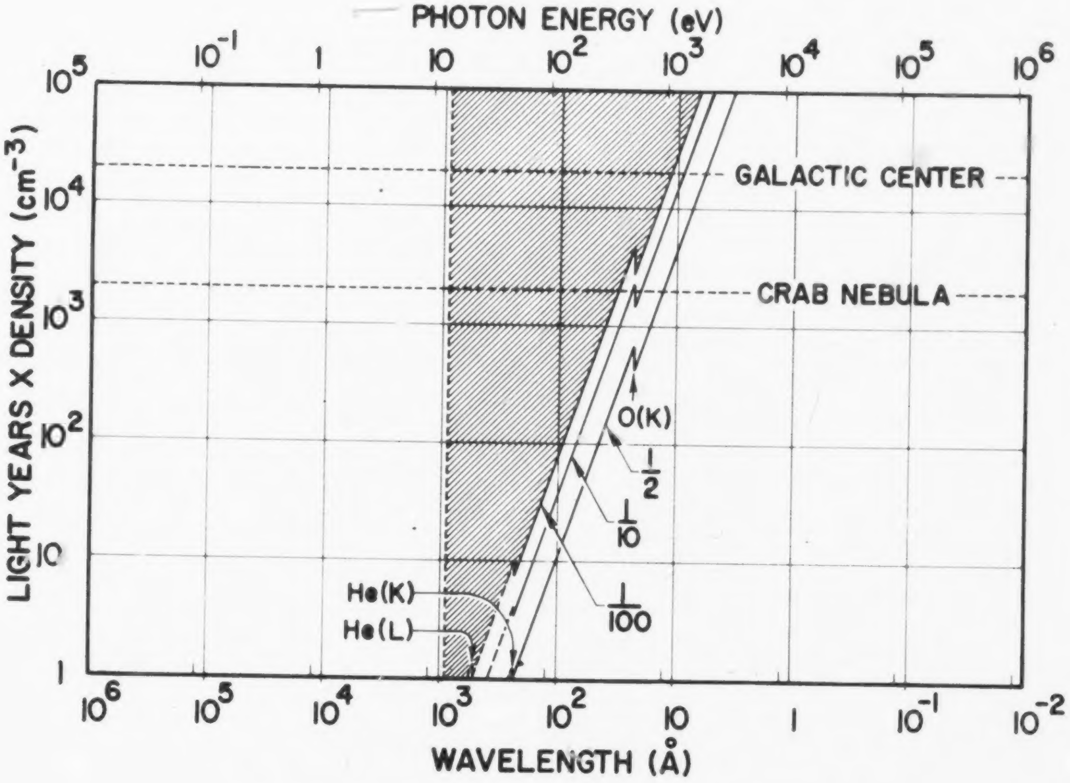


Figure 2. Attenuation of radiation in interstellar space.

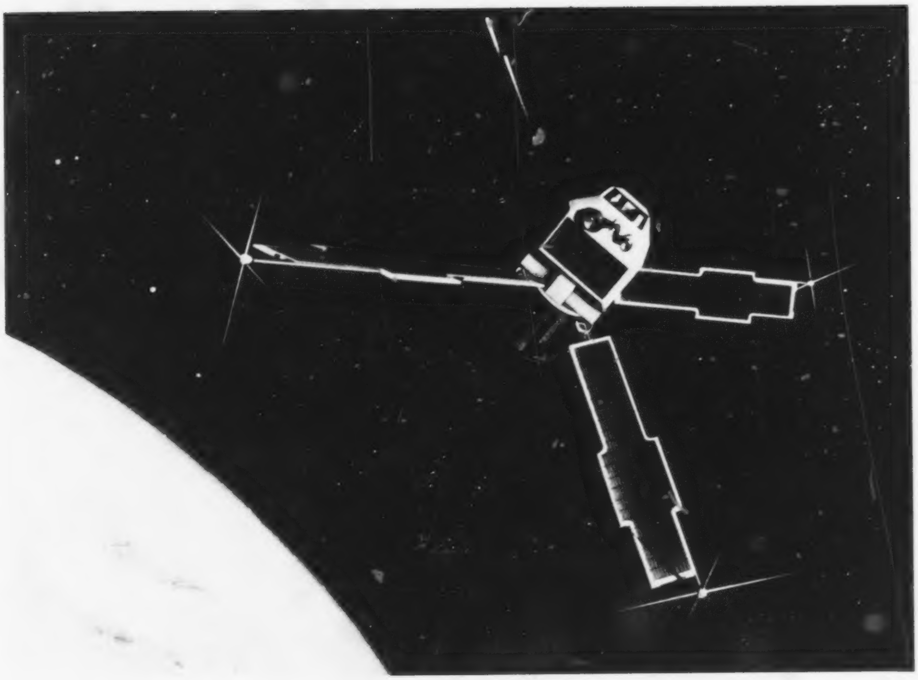


Figure 3. Uhuru.

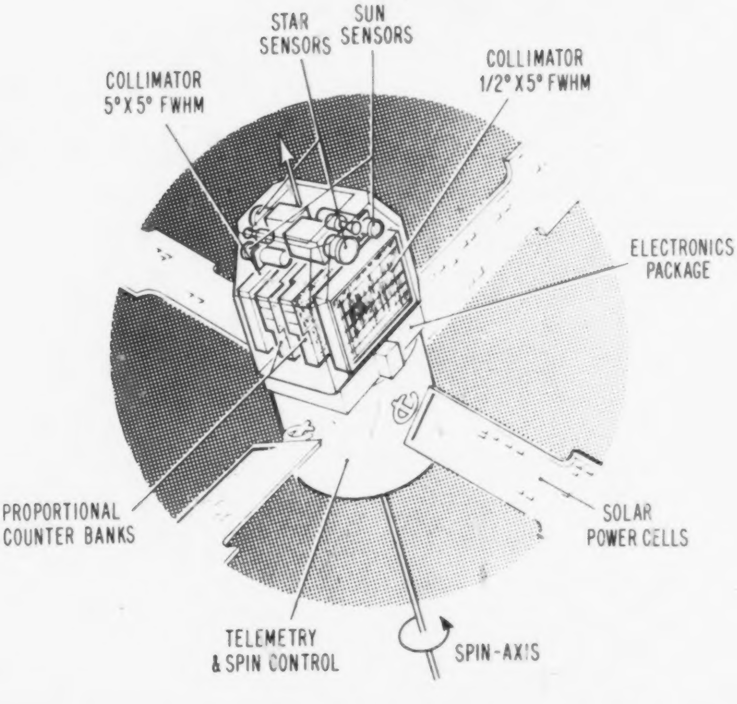

STAR SENSORS
SUN SENSORS
COLLIMATOR 5° X 5° FWHM
COLLIMATOR 1/2° X 5° FWHM
ELECTRONICS PACKAGE
PROPORTIONAL COUNTER BANKS
SOLAR POWER CELLS
TELEMETRY & SPIN CONTROL
SPIN-AXIS

Figure 4. Uhuru's fields of view and scanning mode.

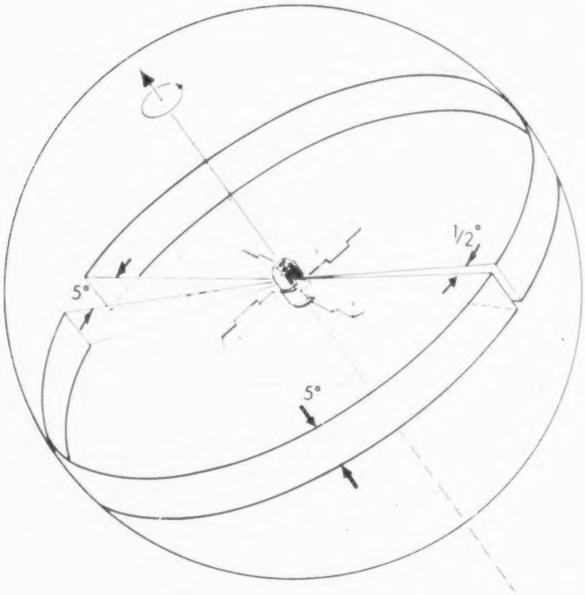


Figure 5. Scanning mode.

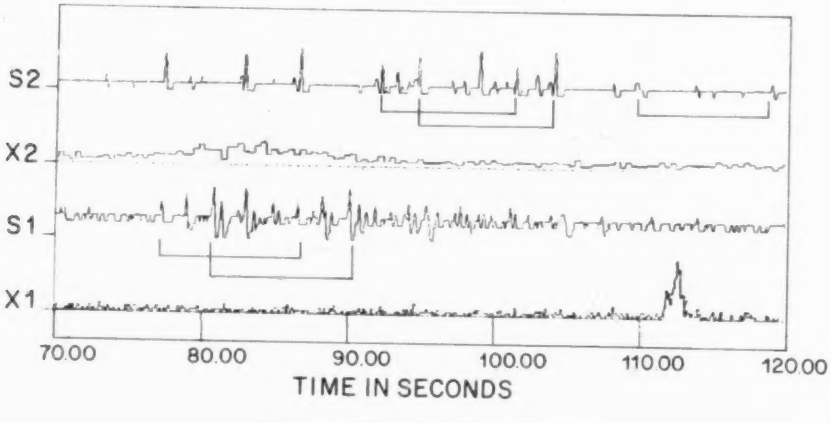


Figure 6. Raw data – day 381.

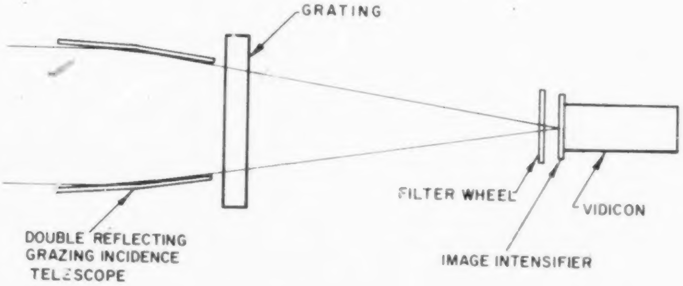

GRATING
FILTER WHEEL
VIDICON
DOUBLE REFLECTING GRAZING INCIDENCE TELESCOPE
IMAGE INTENSIFIER

Figure 7. New method for solar X-ray studies.

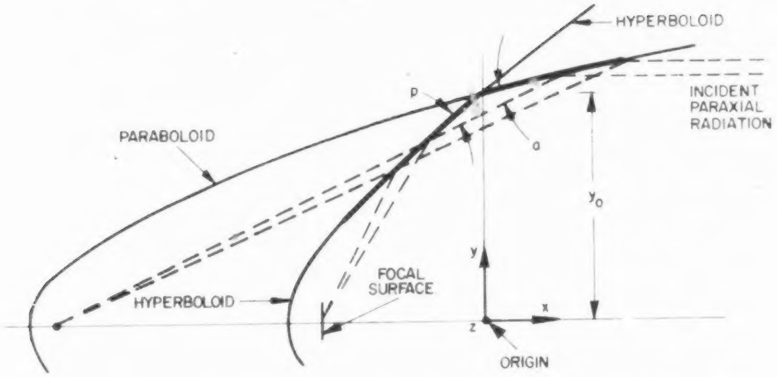

HYPERBOLOID
INCIDENT PARAXIAL RADIATION
p
PARABOLOID
a
$y_0$
y
FOCAL SURFACE
HYPERBOLOID
x
z
ORIGIN

Figure 8. Two reflections from a paraboloid and hyperboloid of resolution.

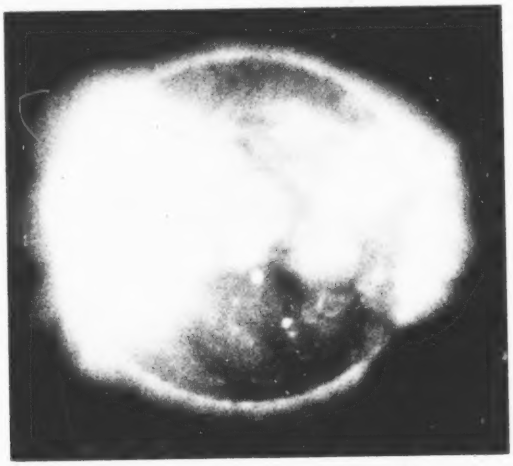


Figure 9. Photograph of the sun obtained with a grazing incidence telescope.

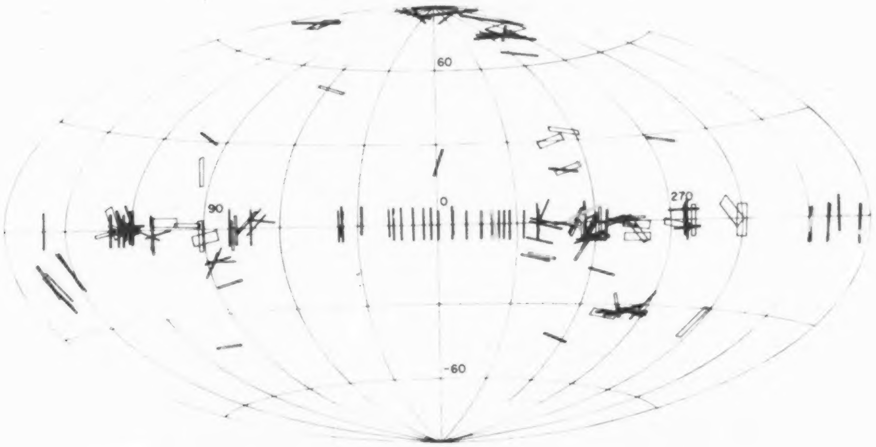

60
90
0
270
-60

Figure 10. X-ray sky from Uhuru — March 29, 1971.

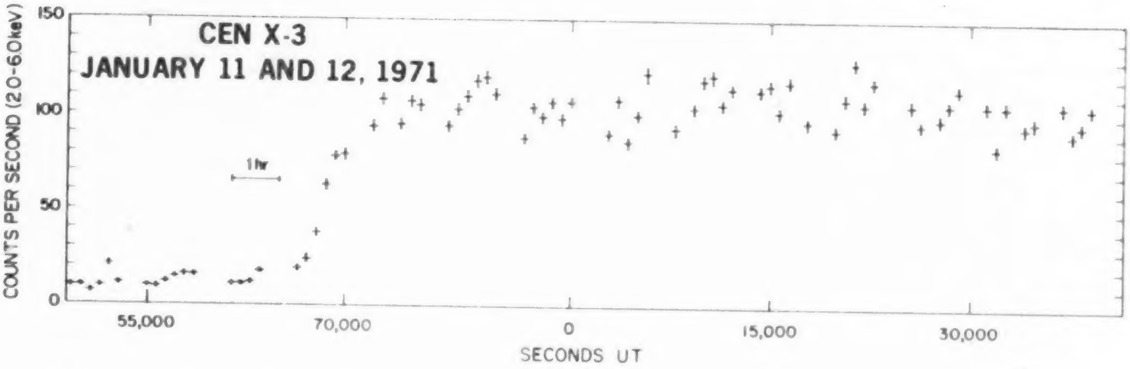


Figure 11. Plot of observed intensity of the Cen X-3 in the 2- to 8-keV energy range during a day.

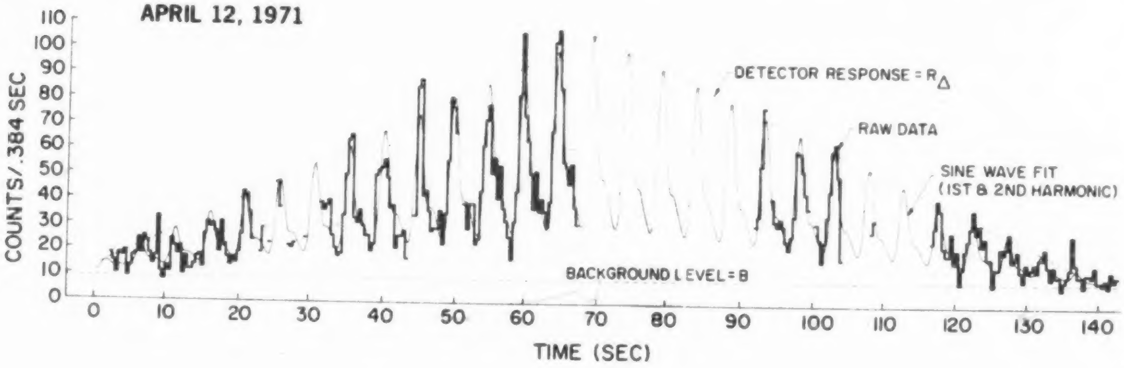


Figure 12. Detail of Cen X-3 emissions.

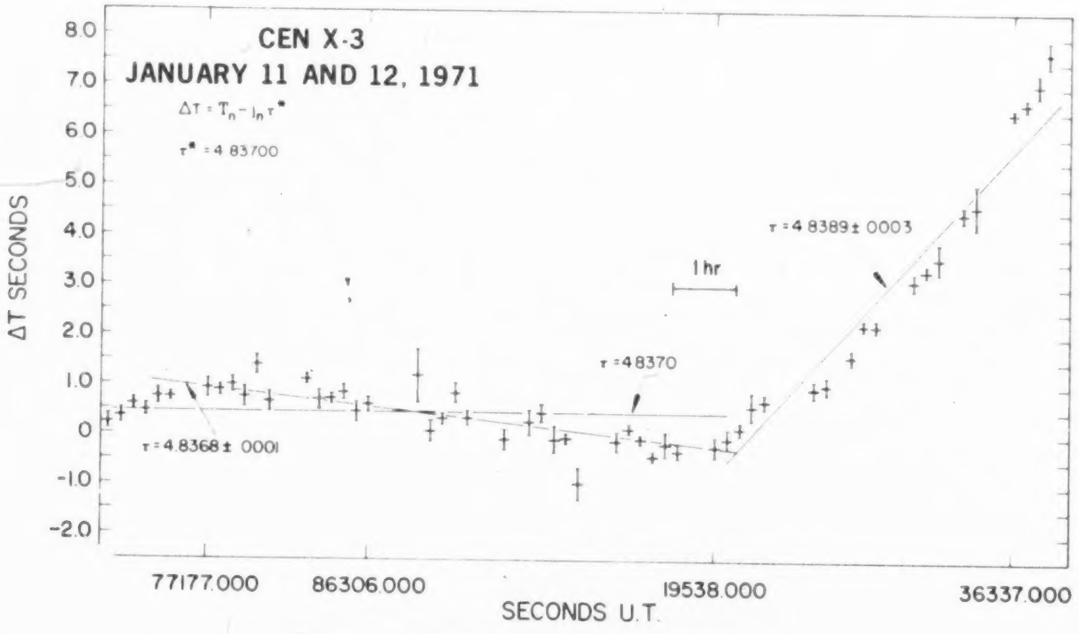


Figure 13. Rapid change in X-ray emission.

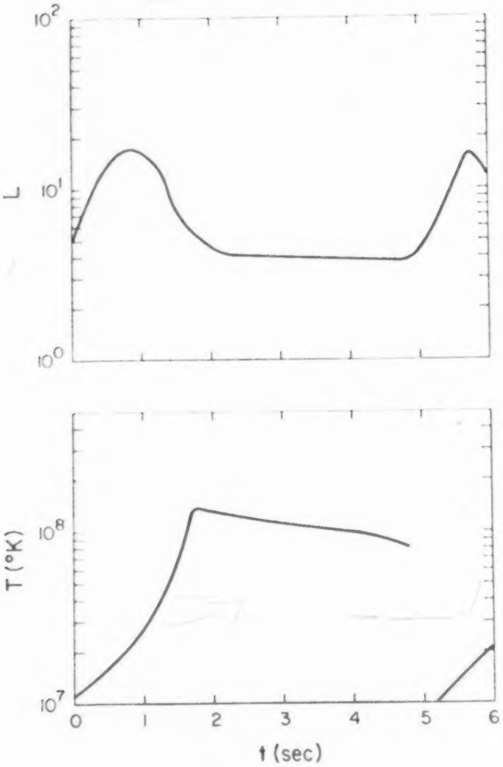


Figure 14. X-ray luminosity and temperature for a pulsating white dwarf.

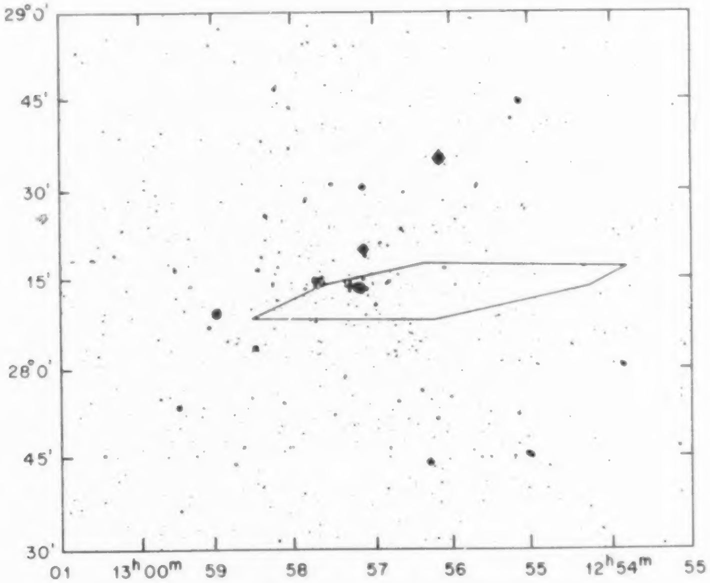

29°0'
45'
30'
15'
28°0'
45'
30'
01
13h00m
59
58
57
56
55
12h54m
55

Figure 15. X-ray source in Coma Cluster.

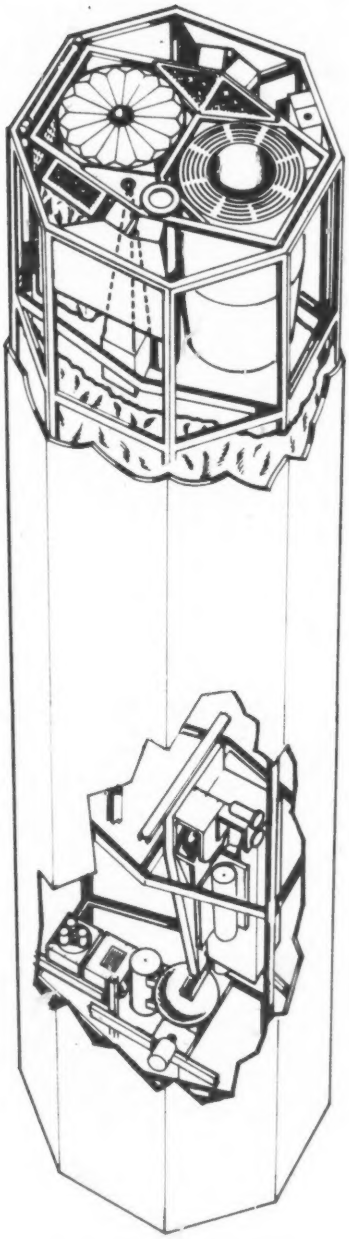


Figure 16. Large focusing X-ray telescope to be used in NASA's High Energy Astronomy Observatory program's third mission.

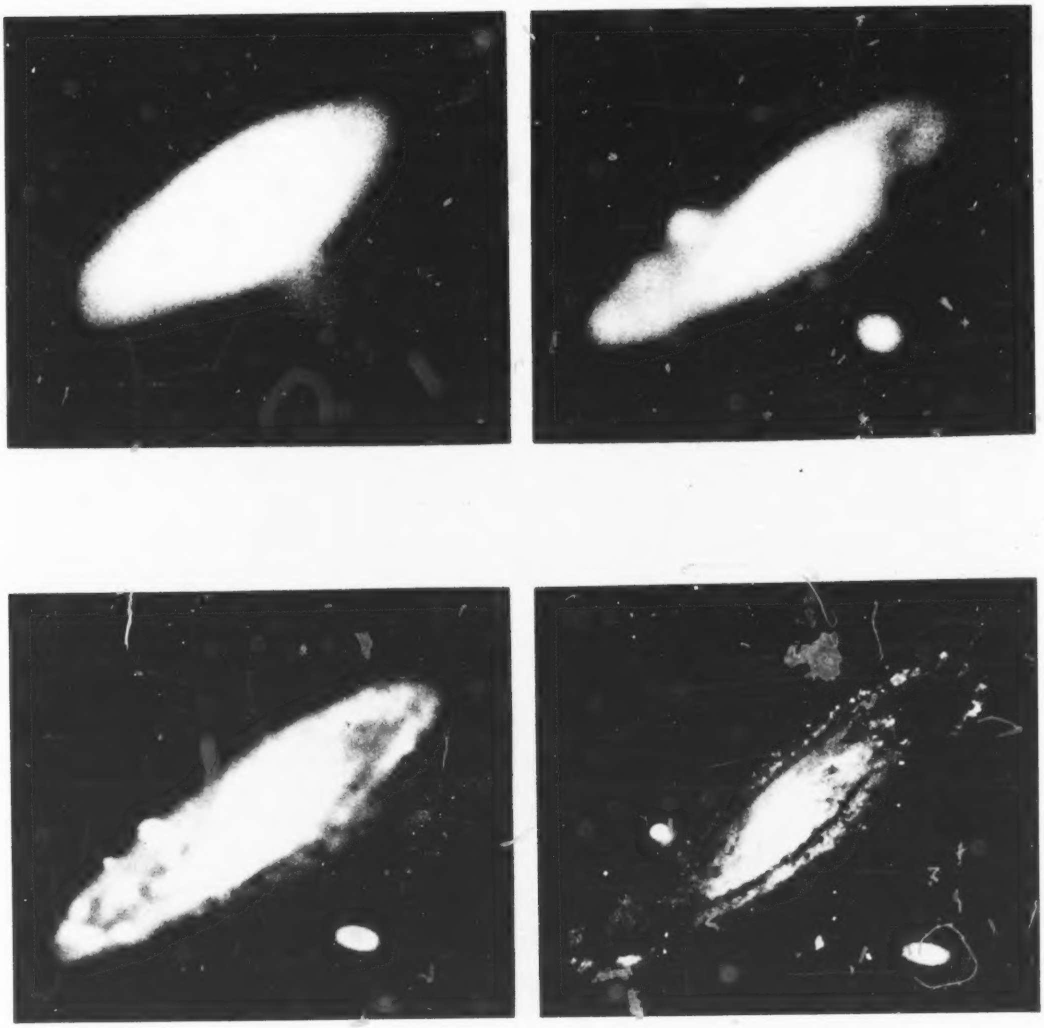
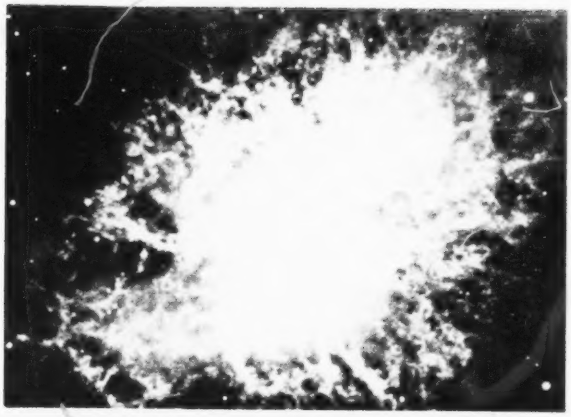


Figure 17. Improvements seen from use of the telescope shown in Figure 16.

Crab Nebula

Distance 1700 pc
$m_V - A_V$ +7
$m_x$(1 - 10keV) $3 \times 10^{-8}$ ergs/cm$^2$-sec
$f_\upsilon$(100 mc) 1700 f.u.
Angular Size 3 arc-minutes

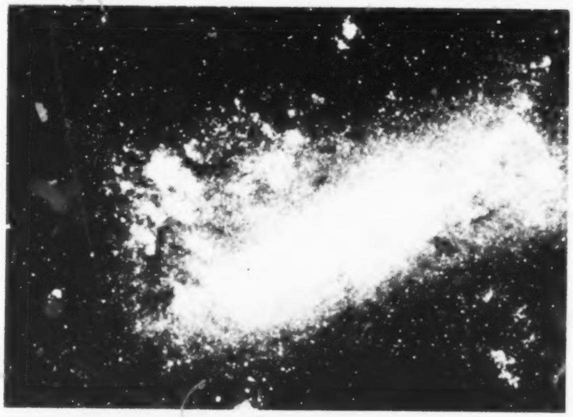
NP0532 (PULSAR)
$m_V$ +17
$m_x$(1 - 10keV) $10^{-9}$ ergs/cm$^2$-sec



Large Magellanic Cloud

Distance 55,000 pc
Crab-Like Object
m +14.5
$m_x$ = $3 \times 10^{-11}$ ergs/cm$^2$-sec
$f_\upsilon$(100 mc) = 1.7 f.u.
Angular Size = 6 arc-seconds

NP0532-like object
$m_V$ = +24.5
$M_x$ = $10^{-12}$ ergs/cm$^2$-sec



M-31

Distance 500,000 pc
Crab-Like Object
$m_V$ = +20.5 mag
$m_x$ = $3 \times 10^{-13}$ ergs/cm$^2$-sec
$f_\upsilon$(100 mc) = 0.017 f.u.

NP0532-like object
$m_V$ = +30.5
$m_x$ = $10^{-14}$ ergs/cm$^2$-sec

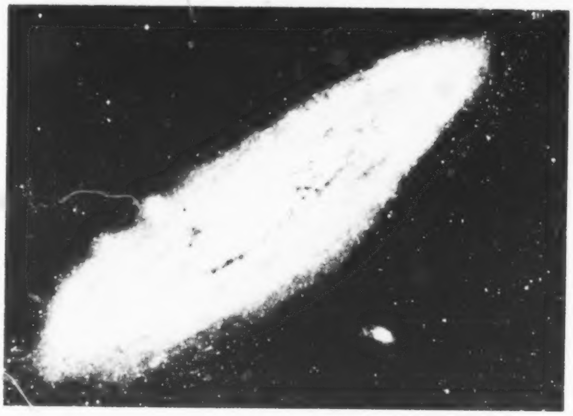


**Figure 18. Improvements seen from use of the telescope shown in Figure 16.**

# BENEFITS OF SPACE RESEARCH TO THE NATURAL SCIENCES

By Dr. John A. O'Keefe
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Laboratory for Space Physics
NASA-Goddard Space Flight Center

I want to begin with the problems that have to do with the practical applications of the studies of the moon. "Are we really on the planet best suited for the human species?" If you ask this question seriously, the answer that suggests itself is that perhaps we are not. As you know, the body plan that we all share here is that of a rather small monkey, sort of bent forward. In this creature most of the soft parts were slung from the backbone where it would be natural, like a suspension bridge. In putting the thing in the erect posture and increasing the mass a great deal, these parts sort of slope down, like a bunch of sacks hung from a vertical pole. It does not work very well. It works, I assure you, progressively worse as you grow older. This is a source of a lot of our bodily difficulties — flat feet, varicose veins, hemorrhoids, and several other things. What I suggest is that a lot of this trouble comes from the fact that we are on a planet on which the force of gravity is stronger than that which would be best suited for creatures built the way we are. Ultimately, the agony of childbirth stems also from this fact. We are trapped in this situation by the rather large force of gravity of the planet that we live on. So I want to suggest that eventually we may find it to our advantage to shift to a planet where the force of gravity is less, and where we do not have this painful problem.

In our office we have been doing some work on the surface of the moon, and Adler has been doing some work on it. One of his ideas concerned an apparatus of about the size of a flat iron which would direct alpha particles down at the lunar surface. Some X-rays would come back, and he would analyze them to find out of what the lunar surface was composed. He never could get approval for that, but, with the aid of Dr. Giacconi, he discovered that the sun sends energetic X-rays down which generate other X-rays, which are characteristic of the lunar surface. In this way he was able to analyze the whole thing by using the sun instead of his apparatus. A great deal of work has been done by this method in analyzing the lunar surface. He has thought that the back side of the moon is mostly anorthosite, something like the Adirondacks. The front side of the moon is confirmed, but everybody thought that there were basalts everywhere. But the most striking thing is that he never seems to find any large amounts of magnesium. The inside of the moon has got to be magnesium, not pure magnesium, but MgO and magnesium silicate, $Mg_2SiO_4$ or $MgSiO_3$. The point is that it has to be made largely of MgO. We have been told that the maria, the great black spots on the moon, are places where meteorites came down and eviscerated the moon, got the guts out, and spread them on the outside. So we should have areas on the moon that are covered with MgO, large amounts of it. But we do not find it; therefore, something is radically wrong.

As you know, right now the almighty dollar is having the worst time since the days of George Washington, when they papered the walls with them. The value of the dollar, in terms of gold, is dropping. This is because of the fact that we are having an excess of imports over exports; we are not making money as a country; the nation as a whole has a net outflow of gold, and that is making trouble for us. It is this trouble, devices that have been developed in the Lunar Program — electronic control devices or computers, both of which were an important part of the satellite program — which are the kinds of things that are now earning us dollars. Those are among the important exports which are not being balanced by corresponding imports. In other words, the U.S. computer industry is earning dollars for the U.S. and is helping us in this dollar crisis. All the other space-related hardware is also earning us money because we have a net of import balance on it. In the hardest, coldest, bloodiest sort of sense, the dollar is being held up by the space industry. You cannot get much more practical than that!

A second field of effort which we have been involved in is the study of impact metamorphism. I will tell this story because I got mixed up in it, not very much, but I was involved in it. About 15 years ago, I went to dinner with Shoemaker out at Ames. We were talking about tektites, of course. Shoemaker handed me a little chunk of rock, rather roundish, and he said, "If tektites come from the moon, you should see things like that, because that is what we found in a meteorite crater and it looks like what would be thrown out." So I took the thing back. Being an astronomer, I handed it to Paul Lowman, geologist, and said, "Shoemaker says if we ever get anything from the moon it will look like this, because this was thrown out of a meteor crater." Lowman sliced it and looked at the thing under a microscope, the way they do. Then he sent the thing over to the U.S. Geological Survey (USGS), because there was something that he did not understand. The U.S. Geological Survey analyzed it by X-ray and they found coesite in it. A little later a fellow from the USGS came over to see me, and he said, "Do you know what coesite is?" "No," I said. He said, "Well, let me explain it. It is a high-pressure polymorph, a high-pressure form of quartz, produced, evidently, by the impact." So I went around to see one of the fellows in my office named McDonald, Gordon McDonald, and asked, "Gordon, do you know what coesite is?" He answered, "Yes, I do." It turned out that he had been looking for coesite in the rocks of the earth for about 7 years and had never found it. This is an effort directly supported by the space effort. We look at this thing, because we were trying to study the moon. But that is not the end of the story.

The first result of the coesite discovery was that we now had a tool by which we could recognize impact craters. Coesite is produced by impact. It is a high-pressure form that takes 16 kilobars. You cannot get that kind of pressure on the earth, except at great depths. The astounding thing was that once the mineral had been recognized, they went out to the meteor crater and found this unknown mineral in carload lots around there. In places it was about 7 percent of the rock. Imagine, an unknown mineral in a well-studied site, available in carload lots! They discovered another mineral, stishorite, in the same place, also formed by high pressure, but this was only available in about 1 percent of the rock. Now with these two minerals, they went to all kinds of places. Shoemaker went to a church in Nördlingen, Germany, on the way to an international congress. The walls of the edifice looked like meteor crater material, so he got a piece from a quarry nearby, sent it back to the USGS; it showed coesite in it. Shoemaker walked into the International Geological Congress and said that this crater — which is some 25 km across, with a whole city sitting inside of it — is the result of a meteorite impact on the surface of the earth. Professor Wagner of Tübingen said, "I have gone over the Rieskessel for 55 years and nobody can pick up a single rock on a Sunday afternoon and tell me what the Rieskessel is." But he was wrong; that is exactly what had happened. What has come out of that beyond this, is the following: There has been a tremendous effort in the study of impact formations of all kinds. We have discovered about 60 impact craters across the world and mineralogically identified them as being of this kind. In addition, De Carli and Jamison in the U.S. said that there are diamonds in the meteor craters, in the irons. And Nininger had stated that those diamonds were probably because of shock. His reasoning was, "If coesite is made from quartz by shock, maybe diamonds can be made from graphite by shock." They got together, and according to De Carli's story as he told me, he took a barrel of water and about as much graphite as it takes to make a lead pencil, and 1 lb of gun powder and made diamonds out of it. These diamonds were very tiny, so tiny that they could not even be used as an abrasive. Recently, we have discovered how to sinter them so they can now be used as an abrasive. By this method, diamonds were produced in pound quantity. It is a new industrial process which will eventually be of great importance. My cousin's wife came out to visit me from Stanford Research Institute a while ago, trying to figure out how she could sell these diamonds for any reasonable purpose. They are so fine that at the time the only thing they could think of was to paint them on the outside of automobiles so that they would not scratch.

Another thing that came out of it was that Harold Urey had a theory which is called "Diamonds, Meteorites, and The Origin of the Solar System." It is published in the Astrophysical Journal, 1950 or thereabouts. The basic idea of this theory was that there are diamonds in the meteorites. This means that the meteorites had to be under great pressure when they were formed. The only way to put them under great pressure was to put them in a center of a body, a large planet. The planet had to be as big as the moon, and therefore, this theory was that the whole solar system was composed of objects which once had been moon size and had been broken down to form the solar system and then rebuilt to make the planets. Well, our idea collapsed because now that we had the coesite, it was clear that shock can make these high pressure polymorphs, like diamonds. There were no grounds to assume any longer that the meteorites had ever been inside very big objects. There was a battle about this issue that lasted about 4 to 5 years. The conclusion was just as I have stated, there is no reason to assume that the solar system was formed this way.

There is another implication. We went out to look at Sudbury. Bob Dietz had been there, and had found some queer looking things around Sudbury called shadowcones. The shadowcones are supposed to be from meteorite impact. So Dietz had suggested back in 1950 that the Sudbury feature was produced by a meteorite impact. Bevan French went out there in my place because he did not believe what Dietz had said, but he came back a believer; he found, in the Sudbury material, not coesite, but some of the other marks of impact metamorphism. I should say that in the 4 or 5 years between the discovery of coesite and the time when French went to look at Sudbury, there had been a tremendous development of this scientific impact metamorphism — not only with coesite, but also with quartz, and especially with Tübingen, in Germany — a development in which they saw planar features in quartz, which are marks of impact metamorphism. So French came back and he identified the Sudbury structure as an impact structure. He has now convinced the other students of Sudbury (and there are some people who study Sudbury with a good deal of enthusiasm) that it is impact. The reason why people study Sudbury with such enthusiasm is that 75 percent of the free world's nickel comes from Sudbury. It is one of the world's greatest mining sites. Sudbury is 25 percent of the mineral wealth of Canada, and the backbone of the International Nickel Company. Billions of dollars have already been taken out of it. So you cannot really claim that information on how such structures are formed is not of considerable practical importance!

We have already discussed the implications of this new science which began — I point out again — as a study directed toward the moon. The whole interesting field of impact metamorphism came out of the lunar study. Until very recently, we have not had actual lunar samples to deal with. We had been thinking about what they would be — we have actually had to think about what the samples would look like, to plan for them. It is out of this planning that this wonderful new work has come.

How does research of this type tie in with cosmology? In the moon there were once tiny blips of nickel iron, which have since disappeared. In the earth, we know where they went; they went to its core. But the problem of problems with respect to the moon is, where is the moon's nickel? Nickel is one of the siderophiles; you would never purchase a nickel ring. Gold and platinum are also gone. Where did they go, where did the siderophile elements of the moon go? The most logical and obvious answer is that they went down to the core of the earth, and the moon is formed from the outer mantle of the earth. I have done some mathematical developments which show that you can make this theory stand up and walk. Thus, through these studies of the moon, we are working backward toward the origin of the solar system. I believe this process of fission, the formation of the moon from the earth, is fundamental to the way in which the solar system itself was formed. Perhaps we can participate in this enormous intellectual adventure that Dr. Giacconi was talking about, in which we study the beginnings of things, both through X-ray astronomy and also through the study of the rocks which lie about us everywhere. If we really look back at the history of cosmology, we see that a key point in it, one that astronomers never acknowledge, was in 1948 or 1949 when Patterson and Urey showed that the earth must be 4.5 billion years old. The astronomers went back and had a quick look at their figures and recalculated the distance scale based upon the Cepheid variables. Everything got switched around and suddenly the universe became a good deal older than 4.5 billion years. That was one of the hard facts — the hinge on which the whole thing turns. Geology can give you hard facts which are mighty useful in the welter of beautiful new results of the type that Giacconi was talking about. You do need a few things that you can absolutely bet on.

Recently, the meteorite people have shown that at the time when the meteorites were formed, there had just been a supernova or something like that — something had produced enormous amounts of fresh nuclear materials, because there was radioactive iodine-129 and radioactive plutonium-124 in the meteorites when they were formed. Which means that 4.5 billion years ago, within a few hundred million years before that — say 4.7 billion years ago, but not earlier than 4.8 billion years ago — there was some kind of a nuclear event producing radioactive material in the immediate vicinity of the solar system, a part of which reached the earth. Thus, when you get the geological background, the rock background, you get a lock of a different kind; a lock that will not be fitted by just any key but only by the right key. So there are two kinds of things that are needed: We need these diffuse observations, and we also need the very hard results that come out of hard-rock studies, because they finally define the thing.

In conclusion, these are some of the things that we hope to get out of the space program. We hope to get new techniques and new devices which will partly support our dollar and partly tell us things about the moon. We hope to see deeper into the origin of the moon, and with it, the origin of the solar system. Eventually, we hope to be able to look back to this event which is at the beginning of the solar system and back toward these fascinating cosmological things that Dr. Giacconi has been talking about.

Transcribed from tape

# THE OUTER PLANETS – FLY-BY PROSPECTS

By Dr. W. D. De Marcus
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University of Kentucky

My topic concerns the question, what might be some of the benefits from the fly-bys of the outer planets. Now, if you are going to study the solar system, one thing that you might talk about is its overall chemical composition.

With that in mind, suppose we took all the known mass in the solar system, threw it into a gigantic blender, ran that blender for a while, and then extracted 1 kg. In that kilogram, if it had been well blended, 998.6554 g would have been solar matter, taking up almost the whole kilogram. I have to use that many figures, although they are not accurate, in order to illustrate some of the things that we are interested in later on. If you could identify it, you could then pull out 1.336 g of giant planet matter, which would include all of Jupiter, Saturn, Uranus, and Neptune. If you could separately identify it you could pull out only slightly less than 5 mg for all the terrestrial planets together, not just the earth alone. The moon, of course, would be almost nonexisting, having such a tiny part in it. If you followed my figures I accounted for all but 2.72 mg of the original kilogram – and that would be Pluto (although that one is still uncertain), all the satellites, the asteroids, all meteoroid matter, dust, comets, and so forth. So, if you really want to study the composition of the solar system in any real sense, obviously you must study the sun. But it is also reasonable to be interested in that part of the solar system which is not the sun, but the next level of division. In doing that, let us go through our blending process again, take everything we know about that is not in the sun, blend it together, and then extract from that. If we pull out 1 kg of blended extrasolar matter, the earth would be 2.232 g. All the extraterrestrial planets together without the satellites would be 4 g out of our kilogram. Jupiter, without his satellites, would be 710 g, which is the biggest chunk of the kilogram. We have Saturn with 213 g of the kilogram. Uranus and Neptune, all lumped together, add another 71 g. We add the satellites, Pluto, asteroids, and all that and we get another couple of grams. In other words, Jupiter and Saturn together have 92.3 percent of the extrasolar matter. The giants together, even without their satellites, have 99.4 percent. For example, all of the terrestrial planets lumped together have only 0.4 percent, and this includes the moon, even though the extrasolar matter have only 0.0027 percent of the matter that is not in the sun itself. So in the same kind of sense, I will not argue that you cannot find out very fascinating things about the moon and all that, but it is easy to lose sight of the fact what a small sample of the solar system the moon represents. On a basis of abundance, this is important.

When we go out and launch our fly-bys by the planets, the question, of course, is what the benefits will be. One benefit is obvious and I am just going to mention it briefly. For a long time, we have suspected that we knew the composition of Jupiter. In fact, theoretical predictions were made long ago which said Jupiter was about 80 percent hydrogen; that was at the time when the spectroscopic evidence indicated that first quantitative estimate was only 1 percent of that. But the theory seemed clear. Other theories tried to shake the model and always ended up with that and just argued that the atmosphere of Jupiter was fooling us. It was composed differently but anybody that really looked at the theoretical problems carefully always came up with 80 percent hydrogen by mass for Jupiter. That seems to be what the spectroscopic people have now homed in on and so now theory and experiment agree. I do not anticipate any change in this in the case of Jupiter, and probably little change in the case of Saturn which has less, although there are worries about Saturn.

Now, in regard as to what else is there, a great deal will be learned, but we already know the big bulk of it is hydrogen and the rest of it probably is a large amount of helium. The amounts of more common elements that we know about, such as carbon and nitrogen that are there, are small. But when you go out to explore these planets, when you go into any new territory, you will start looking at this subject closer. What always happens is that you are going to have surprises. In the following, I would like to anticipate some of the surprises that will occur from evidence that we already have. There is evidence that there are changes still taking place on Jupiter and Saturn. I do not mean that these are going to be major and I do not necessarily mean that these are fundamental changes, but Jupiter is certainly a dynamic source. It is some kind of heat engine. The evidence for that, to my mind, is now indisputable. It reflects sunlight with a semicyclic periodicity that, at least in a straight-back direction, has an amplitude of half a magnitude, which is about 36 percent or so in amplitude of its total. In addition to that, strange things have been seen. Sampson, when he did some monumental work on the Galilean satellites, would have at that time gotten by far the most accurate value for the astronomical constant (until radar came in) except he was hampered by one thing. After he had done all the theories and corrected them empirically and predicted eclipse times, the satellites never eclipsed exactly when they should have. Sometimes they were behind, sometimes ahead — indicating that the surface of Jupiter they were cutting into was fluctuating by something like ±200 miles, and this led to an ambiguity in the eclipse times which stopped his accuracy so that he did not have the most accurate value of the astronomical constant when he had to assign a probable error for that.

Another thing has happened since then — a very great shock. When a man named Eropkin was observing the satellite eclipses photoelectrically, he ran into a very strange phenomenon. The satellites would act like they were going into eclipse at distances of several tens of thousands kilometers above the surface. There would be a lowering in their light curve, then it would go back up to almost full brilliance before they would go into true eclipse. This was repeated from satellite to satellite. Moreover, different satellites entering, because of perspective effects, at different places and latitudes on the planet showed the different height in a very well defined pattern as a much more elliptical structure than Jupiter itself has. But the place from where this light pulse came, was itself ellipsoidal in structure — at least, we saw one dimension of it — so something was obscuring the light from the satellites quite high above Jupiter's surface. This is a great deal higher up than the stuff seen by Sampson. I mention the Sampson work only because it has been disputed if Sampson really saw that, by people who have looked one time and did not find it.

Another thing that sort of confirms this is that between 1920 and 1950 something happened to Jupiter's fifth satellite. One of the great crosses planetary physics has to bear is that fashions change; around 1920, people had been taking spectra and photographs of planets and watching them assiduously and then suddenly they quit and turned to other things. Until Sputnik went up and the space program got started here, nobody looked at them anymore. But the measurements of the fifth satellite were discovered by Barnard. He watched it for several years and his observation, as all of his work, was extremely accurate and well founded. Basically, he quit around 1918 because of circumstances beyond his control. Since then some observations have been taken up in the late forties and some more recently in the sixties, but the upshot is that, now that more data are in, something seems to have happened to the fifth satellite sometime between 1920 and 1950. It is about 3 deg in longitude off to where it should have been and there is no possibility for error here. That may not seem like a big angle over such a long time but it is quite obvious if you look at the observations as they go and the plot curves. Whether there was such a discontinuity or not, I do not know. It is interesting, though, that whatever happened to the fifth satellite also happened within the same general time frame that Eropkin saw this obscuring matter, and that one explanation of the satellite's advance in longitude would have been some resisting dust.

There are a lot of other arguments for the fact that Jupiter is dynamic. I do not want to overemphasize this, though, because in a way I think Jupiter is a much safer object for study right now than Saturn. As for Saturn, I am ashamed to confess that for a long time I had ignored some facts that were right in front of my nose. Saturn has what is called an equatorial current as does virtually everything that rotates, and it has an atmosphere. I will return to this in a minute. But Saturn's current is much more marked than others. Saturn's equatorial current rotates at least something like 28 min faster than the currents at the 38 deg latitude. That is a big effect. Its total rotation period is about 10 hours; if you take a half hour off that, you get a major equatorial acceleration.

A long time ago, some spectroscopic work was done on it. In the same way that one measured the fact that Saturn's rings were not measuring rigidly, the man just placed a spectroscope slit on the equator of Saturn and then placed it at various latitudes. From the tilt of the spectral lines we can get the rotational period of that particular latitude. His conclusion concerned the poles, although he did not look at them. Considering the way we have to lay our slit, we would not get any light at the poles. He got, in fact, a 60 deg latitude but that is higher than any observation has ever been. His conclusion was that the poles might be rotating as much as 1 hr less than the equator. If that is so, most of the theoretical work that has been done on Jupiter and Saturn will have to be looked at again very carefully, because that has been based on the assumption that the body was at least partially and to some fair degree of accuracy in hydrostatic equilibrium. But hydrostatic equilibrium requires rigid body rotation. You can put up with some departure from that because you know on general grounds that atmospheres and oceans with energy budgets either from within or without cannot rotate in hydrostatic equilibrium. But 1 hour out of 10 hours is too much to swallow. There are many speculations. One explanation is that Saturn is at the present in the process of collapse, at about 10 percent in radius. It is still doing it and therefore is speeding faster inside than outside. The speedup, to my mind, would feed primarily into the equator and then diffuse to the poles from that source. This would explain that pattern. On the other hand, though, it may be that for some reason that we do not know, the true period of rotation is more like what the poles would be if this work is right. I understand that McDonald in Texas is going to redo this work much more accurately to see if this is so. The spot work generally tends to confirm it, but the spots do not go to high latitudes, and so we do not know what is going on.

I would now like to talk a little bit on one quite definite topic which is common to the earth, the sun, and the giant planets. It is the fact that all the planets that we know about, the Earth, the Sun itself, and Jupiter and Saturn, have these phenomena called equatorial accelerations. In the case of the earth, this has been debated in the past and it has, in fact, been said that it is the other way. I believe that the latest word on that is that the earth really has an equatorial acceleration. This is a bad term, but if we average the wind velocities on the earth's equator over every year equitably and then average them over the years, the average wind speed at the earth's equator is rotating in the same sense as the earth but faster. At first the meteorologists had a negative equatorial acceleration. They said, the average wind at the earth's equator was actually slower than the earth was turning and that it was blowing the wrong way. But they averaged all their data without regard to seasons, and they had a whole lot more summer data than winter data. However, it requires both of them to make the average come out right. The sun has an equatorial acceleration of some sort. We know that its equator, at least, rotates faster than the poles, and it is very smooth and very well defined. As for Jupiter, we have this equatorial current there which rotates about 5 min faster than the rest of the planet. Jupiter has all these other belts that rotate with somewhat different periods but they differ very, very slightly among themselves — never by as much as half a minute. Basically, a crude picture of Jupiter's rotation is that the equatorial belt of about ±10 deg rotates 5 min faster than everything else. The behavior of the other belts is also confirmed by the periodicity of the radio emanations from them. If we believe that the radio period is in some sense the true period for Jupiter, its equatorial current is indeed a fast current, running faster and real. When we come to Saturn, we do not know.

Recently there has been introduced in the field of hydrodynamics a new term that is somewhat dangerous and somewhat analogous to old electrical engineering terms where they used the concept of negative resistance in talking about certain kinds of oscillators. Negative resistance is, in principle, manifest in the laser; in fact, the laser does have negative resistance but that is not what they are talking about here. The hydrodynamicists finally realized that you can have negative viscosities in a real and literal sense, specifically when you have turbulent motions. I will not go into the mathematics here but we have a system called Reynolds stresses which is really not related to molecular viscosity at all except on a much more fundamental level. In the past we have always used those stresses when we talked about a turbulent viscosity and a turbulent diffusion coefficient. These properties are always many, many powers of 10 higher than the molecular properties when we talk about turbulent viscosity. But if we analyze it in detail, because of the correlations and exchange of these packets, in normal situations the Reynolds stresses do act like an ordinary viscosity and they tend to equalize the mean flow motions. There is no intrinsic reason that you can think of offhand as to why these stresses could not, in fact, cause two streams of water or fluids that are going in opposite directions, with respect to each other, to actually accelerate their disparate velocities. Now you may say, "That is not normal, that does not make sense." Some of the measurements that were made on the sun early in the game and detailed analysis showed, in fact, that the eddies seemed to be doing this. I do not really know whether that has stood the test of time or not and I do not really care because such a phenomenon is possible. Even if the sun is not doing it, it does not mean that it is going on on the major planets, although it would be nice to think that all the explanations were the same. But we cannot do that because Jupiter and Saturn have too different a structure even though they both have equatorial currents.

Often in the past and in the present it has been noticed that two-dimensional turbulence often leads to surprises. In turbulence, as a rule and tendency, as everybody knows, if you suddenly cut off whatever it is that is causing it to be turbulent — the energy supply — the tendency is given by the old paraphrase of De Morgan, "Big whirls have little whirls which feed on their velocity, and little whirls have lesser whirls and so on to viscosity." I think I am quoting that right. But, in two dimensions, this may or may not be true. Two-dimensional turbulence may be normal in the sense that what is going on inside when it is in steady-state, if you look at the inner workings, or what would happen if you suddenly cut off all energy sources and watched it decay, it might just be normal in that sense — that bigger whirls are feeding lesser whirls which feed lesser whirls and finally, viscosity dissipates them on the one end. There is a lesser scale of turbulence possible in two dimensions, also in three, where after cutting off the disturbance everything would die just as it is and pretty much independently of everything else. That would be low Reynolds number turbulence, and in that case you would have, after a while, big vortices left, at least big circulations, which would survive, but they would have been there already and they would not have grown.

The other case which I would like to come to is that, in two-dimensional turbulence you can have things going on inside where, after cutting off the energy supply, the reverse would occur, namely, big whirls would tend to coalesce to form yet bigger whirls which would tend to coalesce to form yet bigger whirls. This would be the natural thing to do. Now, what is natural? Natural means, when you really analyze it, that things are in accord with the second law of thermodynamics. And this, as a fluid dynamicist would also say, is the case for negative viscosity — this coalescence of whirls being exactly the opposite of what happens in normal turbulence. The fact that in two dimensions you can have this phenomenon occur where big whirls grow — the tendency is to grow — is in natural accord with thermodynamics. In a paper in 1949, a man wrote very profoundly on statistical hydrodynamics. This paper is not nearly as well known as it should be; in fact, it is hardly known at all even though its author subsequently won the Nobel prize only 2 years ago — not for this work but for his work in the general field of statistical mechanics. The author was Professor Onsager of Yale. He discovered that a system of two-dimensional vortices — if you cut off viscosity, which is legitimate — had equations of motions which could be technically written in what is called Hamiltonian form that with appropriate treatment could be defined as a very convergent Hamiltonian. He treated this system of a finite number of two-dimensional vortices confined to a finite area by the methods of statistical mechanics and concluded that, if the energy per vortex was below a certain amount, the behavior of these strictly two-dimensional systems was normal in that the tendency was for big whirls to break up. This was with no viscosity. In the real treatment of turbulence, in the region where it occurs, the actual viscosity plays no role. But then he went on and he said that if you put so much energy into this system, into the turbulent motion, so that the energy per vortex exceeded a certain amount, big whirls coalesce.

I will not go into any further details. All I am saying is, you may not like these negative viscosities because they go against the grain, but at least in one case, we have a very careful theoretical treatment by a man who won the Nobel prize for statistical mechanics and who says that this is the second law of thermodynamics; some two-dimensional situations will dictate this if the energetics of the system are high enough. I would like to tell you a little bit more about these negative viscosities because they would explain these equatorial accelerations, but they would not tell you why Jupiter is belted, why its velocity of rotation is pretty much constant in belts and then, suddenly, has small discontinuities, then finally gets down to the equator and breaks loose, and why Saturn — which has a fairly sharply defined equatorial current, but not perfectly so — has its rotational period change fairly smoothly above that current, and whether or not it flattens out around 40-some degrees and stays constant being already 0.5 hour faster than the equator, or whether it goes on to the 1 hour difference that would come from Moore's data.

The question of Jupiter's Red Spot has been one of the most tantalizing puzzles in the history of astronomy. In speaking of surprises, this speech was already prepared before I received recent communications on a possible solution of the mystery, but one thing I would say is that solving the mystery of the Red Spot is as easy as Mark Twain said it was easy to quit smoking, namely, that he did it every day. People have solved the Red Spot mystery over and over and the present speaker is not innocent of that because the present rash of so-called "Cartesian Diver Red Spots" rests half on my shoulders and half on Rupert Wildt's because we were the first of the "Cartesian Divers." But that theory was shot down recently by one man with one word and all "Cartesian

Divers" with it. However, it is easy to get theories on the Red Spot but it is not so easy to prove them. I do not really believe that when we get to Jupiter that we are going to be surprised. A lot of things that go on there concern the field of hydrodynamics of rotating fluids, and they are going to bear fruit here on earth.

I do not believe the Red Spot is going to be a surprise. I think that, because it is so outrageous, we have been trying to find outrageously complicated explanations or bizarre phenomena. The kind of thing that makes the Red Spot has probably been going on on earth under our noses all the time. The Red Spot could be something like a hurricane. Ordinary hurricanes are driven by water vapor condensing, which is their heat source; however, that is not going to drive Jupiter's Red Spot. But whether it is cyclonic or countercyclonic does not matter as long as we have some condensing mechanism. Thus, I think that once we understand hurricanes thoroughly, we will understand the Red Spot.

You will say, "What about the fact that hurricanes die?" Well, do you know that hurricanes die? Suppose, for example, when a hurricane is born out in the Caribbean, we could use some imaginary device that would keep it there without interfering with its internal workings — that we had some kind of hurricane swatter that could swat it back to the place of its birth without allowing it to get over land or to go way up over oceans into Arctic waters where it becomes hard to feed on water vapor because the pressure vapor gets low. Would it then die? Do we have any reason to believe that hurricanes die? We know that hurricanes are born in the Caribbean and die there. On the other hand, though, there are hurricanes that start up there and act like they are going to die there and the U.S. Weather Bureau says, "Relax." Then all of a sudden, they rev up again and come in and smash the coast. Well, all of this is contained in some of the most recent theories I know of. One of the very recent theories I am familiar with says that hurricanes are locally stable but globally unstable. Global is a mathematical term borrowed from topology and does not have any direct reference to the globe of the earth, although the way it got into the usage, I guess, was related to the total earth's surface. An object that is locally stable but globally unstable will do exactly what I have said, in principle. It can live indefinitely because it is always stable locally but the elements for its destruction are always working somewhere in the total dynamical structure with which it is involved. They are like glass, for example. Glass is unstable but locally stable, and it lives for a long time. Things that are locally stable but globally unstable can virtually live forever. There is good evidence, to me, that hurricanes would live, occasionally, virtually forever if they did not get over land where their energy supply runs out or if they did not get over Arctic waters. One of them even crossed Mexico once, I believe; it crossed the land barrier, almost died, got into the Pacific, revved up again and, finally, died only considerably north of San Francisco. They do have a tendency to live. Thus, it is hard to shoot down this hurricane idea on the grounds that the Red Spot has been too long-lived to be a hurricane, because if a hurricane cannot wander, it may live forever.

Transcribed from tape

# THE HUMAN VALUE OF SCIENTIFIC INVESTIGATIONS OF THE ORIGIN AND EVOLUTION OF THE SOLAR SYSTEM

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We are in a period when the focus is on reevaluating our priorities with the objectives of redirecting our resources and activities toward solving human problems, rather than problems of a nonhuman and purely materialistic nature. We question the value of space programs to mankind in terms of using both financial and human resources when we are burdened with so many earthbound problems, such as poverty, hunger, overpopulation, pollution, disease, and urban blight. We ask if a space program is relevant to human needs?

The HATS Space Congress has addressed this and other questions, and established the relevance of space programs to human needs on all fronts by revealing an incredibly large spectrum of technological benefits which are directly related to social, political, and economic problems. These technological benefits, however, provide primarily material benefits, but we should note that there are also intellectual benefits for scientists and other scholars, in addition to the less obvious psychological and even spiritual benefits for all men. These benefits are related to the age-old human questions such as "Where do we come from?" "Will mankind endure?" "What is man's future?" "What is our place in the universe?"

These human questions, however, typically arise from man's fears and curiosities. They have remained for all times in midst of social, political, and economic issues that change, not only on a daily-to-yearly basis but every decade and every century.

The significance of such questions were, no doubt, manifested by the Apollo VIII crew when they responded to man's first awe-inspiring views of earth from deep space with phrases such as "The Good Green Earth" and their Christmas message from the moon with reading of the Genesis. At a time when the world was ready to pull itself apart, it spiritually united when Apollo VIII arrived at the moon, and reunited again when Apollo IX landed on the moon. The meaning of the historic words of Neil Armstrong, as he descended onto the lunar surface, "That's one small step for a man, one giant step for mankind" is that man can finally accomplish near impossible tasks through collective efforts of many - not only materially, but also intellectually, psychologically, and spiritually.

## Human Questions and Man's Fears

Most of the life on the earth exists in a biosphere; i.e., shell of life, about 2 miles thick. It extends from the continental shelves, onto the land, and into the lower regions of the atmosphere. Manmade wastes of all sorts have and are still contaminating the biosphere to such a level that all life on earth is endangered. The realization of imminent catastrophe has precipitated some men's fears to a point of near panic. We ask "Can the world be saved?" The answer is probably yes, with the aid of modern technology, and particularly that of space technology; e.g., the development of nonpolluting power systems, waste management control systems, recycling waste materials, etc. This capability can and should be applied to the eradication of manmade biosphere contamination. It, in fact, is probably the most effective means of quickly eliminating contamination or pollution without impairing (if not destroying) civilization, itself, because of an overemphasis of technology reduction.

On the other hand, man is not the only threat to life on earth. Nature occasionally assumes that role as well, bestowing a variety of catastrophes over many regions of the earth, such as tornadoes, hurricanes, earthquakes, volcanoes, tidal waves, not to mention an ice age or two, and more. These have resulted in both animal and human disasters throughout recorded and unrecorded history and have precipitated man's fears of nature's wrath.

In view of the current concerns with manmade pollution, natural pollution catastrophes should be recognized as being relevant to the manmade pollution issue. In terms of the overall ecological question, one should also recognize our uncertainties as to the causes of the extinction of the mighty dinosaurs and the ice-age mammals, in addition to the extinction of their ecological systems. What caused their extinctions? Is the earth evolving such that living species, along with their ecological systems, will eventually be discarded by nature and perhaps replaced by new species and new ecological systems?

A significant example of the destructive powers of nature is the volcanic disaster at Krakatau, when on August 27, 1883, a catastrophic explosion propelled ash 50 miles high, over 300 000 square miles, and generated 120-ft tidal waves which took the lives of 36 000 people in the neighboring coastal towns of Java and Sumatra. The explosion could be heard within a radius of 3000 miles and the resulting pressure waves were recorded around the world. The air became so polluted with expelled ash that the surrounding region (50-mile radius) was in total darkness for 2.5 days, and the entire world experienced spectacular red sunsets for over a year, because of the fine dust which rose high in the stratosphere and circled the globe several times. Similarly, the eruption of Vesuvius in A.D. 79 destroyed the ancient cities of Herculaneum, Stabie, and Pompeii. It is interesting to note, however, that the inhabitants of Pompeii were killed not with molten lava but with natural air pollutants: poisonous gas and ash which buried Pompeii under a layer 12 ft or more in depth.

Consider even further the recent near-encounter with the asteroid, Icarus, which passed some 4 million miles from the earth. This raises additional questions concerning potential hazards that the solar system may impose on mankind in the course of time. One can certainly raise the question "Have catastrophic events occurred on earth or other planets as a natural result of solar system evolution?" In addition, comets, historically, have been considered as signs of disaster and catastrophe, announcing the death of kings, the destruction of kingdoms, pestilence, and famine. Are such fears based on mere superstition or have comets been responsible for an unidentified human catastrophe somewhere in the recesses of man's unrecorded past? One can certainly ask the question as to whether or not nature's wrath will one day unload a new unexpected catastrophe on the earth and eradicate our ecology (if not the earth itself), in spite of man, rather than because of man: probably not, but who can actually say? Our knowledge of the solar system, including an understanding of earth evolution, is too incomplete at this point in time to predict our future with any real certainty.

If man wishes to protect himself from the adversities of nature, no matter what the cause, he must understand her. In order to understand her, he must understand her laws, he must complete his understanding of the solar system evolution and be able to predict not only solar eclipses, magnetic storms, and the weather, but any phenomena good or bad, known and unknown, which affects the evolution of earth.

## Human Questions and Man's Curiosity

In addition to man's basic fears, his insatiable curiosity has precipitated ancient and medieval intellectuals to provide rational philosophical and religious answers to these human questions. Moreover, renaissance to modern time philosophers and scientists have provided some empirical or scientific answers to these questions that have resulted in additional benefits of quasi-accurate disaster predictions, which in turn, provide man with some control over his destiny. In other words, man's curiosity has driven him to explore nature both rationally and empirically, providing him with some means of self-preservation and subsequently, some psychological benefits, with corresponding intellectual benefits.

All is not solved, however, and these same human questions remain; but they can be translated into a more manageable set of scientific questions which, by their very nature, are capable of being answered. Such questions are:

How is the earth evolving?
How is the solar system evolving?
How is the universe evolving?
How is the life evolving?
What is the origin of the earth, the solar system, the universe, life?

We ask "Why investigate apparent esoteric scientific questions concerning the origin and evolution of the earth and the solar system as a whole?" The answer to this question is not only to satisfy man's insatiable curiosity concerning his origin and evolution, but also to mitigate his fears by addressing related questions of the age-old human question of his destiny, identity and purpose, as well as the contemporary question, such as "Can the earth be saved?"

## Attempts to Answer Human Questions

Since the 17th century, many theories have been formulated in attempts to address questions of the origin of the solar system, with a minimum emphasis as to its evolution. Figure 1 [1], for example, lists some of the originators of these theories. These theories, each in their own way, have attempted to account for the existence of the solar system by using data from astronomical observations available at that time in terms of known laws of nature.

In recent times, contemporary theoretical scientists have suggested that some objects of the solar system may provide more information as to solar system origin and evolution than others. The oceans and atmosphere of the earth, for example, have washed away much of the earth's past history, but the moon may have undergone relatively minor changes in the past few million years and, therefore, possesses permanent records of the sun's activity; i.e., sun evolution, and the solar environment to which the earth, as well as the moon, was exposed; i.e., earth and moon evolution. The asteroids are regarded by Alfvin [2] as being structured with preplanet material; i.e., primordial. He has also suggested that an exploration of the brick-shaped asteroid, Eros (which will pass close to earth in 1975), may provide a key to the origin of the solar system. On the other hand, others have speculated that the existing asteroids are reminiscent of an exploded planet. The resolution of these questions is vital in determining asteroid origin and evolution. The giant planet, Jupiter, has been referred to by Rasool [3] as "the Rosetta Stone" of the solar system and may be inhabited with the most primitive forms of living material. This belief is supported by many in the scientific community.

## Nature of the Origin of Evolution Problem

Thus far, all theories of the origin and evolution of the solar systems have taken us only from total darkness to the shadows of dawn. Each theory is, in one way or another, incomplete and considerable observational data are required before we will understand each one.

Any theory of the origin of the solar system as well as its evolution must be capable of explaining both the regularities and irregularities of the solar system in order to establish a high level of scientific creditability; e.g., the fact that all planets of the solar system are in nearly the same plane excepting Pluto. Moreover, all solar system models must take into account the fact that the solar system models consist of entirely different kinds of objects, ranging from atoms of gas and microscopic dust grains to the sun (a star), which is a massive nuclear inferno. Table 1 lists the class of objects which make up the solar system.

Figure 2 pictorially relates the sizes and distances of the major solar system bodies. Figure 3 relates some of the larger minor bodies with some of the smaller major bodies. Jupiter's Red Spot (Fig. 3) is about 3 times the size of the Earth; Mercury and Mars are seen to be comparable in size to the larger satellites of Jupiter and Saturn; and finally the larger asteroids, Ceres and Vesta, are seen to be comparable in size to some of the smaller satellites of Jupiter and Saturn. It is the origin and evolution of these bodies, to which we refer when we speak of the origin and evolution of the solar system.

An examination of the various origins and evolution theories (e.g., those in Figure 1) clearly indicate, however, that there is no single object to be explored and no critical tests that can be applied to assert or deny any one theory or model. Each theory has sufficient freedom to permit the incorporation of almost any new observable data. Advances can be made, however, by attempting to understand the fundamental elements which structure these theories. These elements are the physical processes which have operated and are still operating to produce the present state of evolution of the solar system from its initial state or time of origin. The physical processes by which solar nebula became fractioned, for example, to produce the small but dense terrestrial planets and the giant gassy outer planets is a common element in all theories. It must be understood in great detail if an enhanced understanding of the origin and evolution of the solar system is to be made. It is only through a thorough understanding of all relevant physical processes that will enable mankind to understand the actual evolutionary procedures that occur in solar system formation and evolution. All theories combine many of these processes, most of which are only partially understood, and all are incomplete in one way or another. This situation would be considerably improved, however, by relating theories with measurements to acquire new observational data. Figure 4 [4] shows this relationship, which, in essence, says that theories are structured from our understanding of the physical processes: the better we understand them, the better the theory. But in order to understand these processes, we must collect certain kinds of information which is limited by the kinds of observations that can be made and is, itself, limited to the measurement techniques available. There is no doubt that if we can observe the solar system from various observation points, such as space missions provide, and utilize available measurement techniques, we can obtain the much-needed information required to understand the physical processes governing the evolution and origin of the solar system.

## The Benefits of the Space Age in Addressing Science Questions

The Space Age has opened new investigative horizons for modern science by providing the capability of placing instruments at new on-site observation points (i.e., in situ observations) to see the solar system as it actually is and allowing scientific investigators to collect otherwise unobtainable observational data of the solar system. The use of space exploration may, in fact, be the only viable means of addressing questions of the origin and evolution of the solar system and ultimately answering the related human questions discussed above.

The National Academy of Sciences and Presidential Scientific Advisory Committees, in recognizing the investigative capabilities provided by the space age, has recommended that future space efforts be directed toward questions of the origin and evolution of not only the solar system, but also of the large scale universe, of life itself along with the discovery of extraterrestrial life, and with particular emphasis on exploring the near-earth terrestrial environment. They further recommend that these space efforts be regarded as national goals [5, 6].

These recommendations are certainly in line with previous space activities, such as the International Geophysical Year (IGY), conducted in 1958, the exploration of near-earth space, the discovery of the Van Allen belts, and the retrieval of lunar rock and soil samples with the Apollo program.

## The Human Value of Scientific Investigation

To clarify and answer the questions "What good are lunar rocks?" and "Who can profit from Moon rocks beside scientists?," one should recognize that stellar observations have revealed that there are many unstable stars in the universe which periodically flare up expelling mass in its near-environment that would have catastrophic effects on nearby and associated planetary systems. We may certainly ask the questions "Will the sun suddenly erupt and destroy life on the earth? Is the sun stable enough to support life over extended time periods? Is there any sign that fluctuations in the sun could affect ecological systems on earth?" Prior to the space program scientists typically held the opinion that the middle-aged sun was a stable body having a stable lifetime perhaps 10 to 11 billion years. The lunar rock samples have certainly confirmed these opinions to some extent by showing that today's sun and the sun of a million years ago have not undergone any appreciable change. The answers to additional questions concerning the earth's evolution as a result of the sun's evolution will no doubt provide greater visibility in course time, as we play back the records of time with further lunar exploration, including lunar rock and soil analysis.

Designing future space missions which meet these science goals will no doubt generate new questions and new mission requirements (Fig. 5).

In addition to further explorations of the Moon and our nearest planetary neighbors, Mars, Venus, and Mercury, the grand tours of the late seventies to the giant outer planets, along with future asteroid and comet missions, will provide a wealth of new information on the basic processes involved in the operation of our solar systems (Figs. 6-10). This information will further provide man with the greatest visibility he ever had since the beginning of time as to his origin and evolution. While it is obvious that such missions will be of direct benefit to the natural sciences, we ask "What is the human value of scientific investigations of the origin and evolution of the solar system?" The answer is that science can help man to answer his age-old human questions by examining the bridge between our human questions and science questions and recognizing that both sets of questions are, in a human sense, the same questions.

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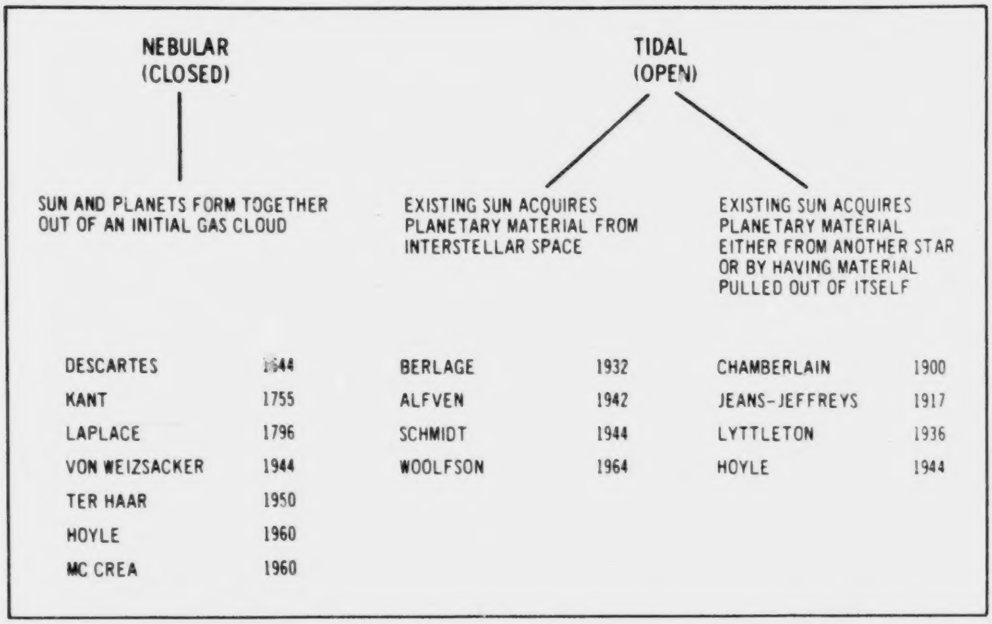
TABLE 1. SOLAR SYSTEM OBJECTS

| | |
|---|---|
| ● SUN | (A STAR) |
| ● TERRESTRIAL PLANETS | (5) |
| ● GIANT PLANETS | (4) |
| ● SATELLITES | (32) |
| ● ASTEROIDS | (30,000) |
| ● COMETS | (580) |
| ● METEORITES | |
| ● DUST & PLASMA | |



NEBULAR
(CLOSED)
TIDAL
(OPEN)
SUN AND PLANETS FORM TOGETHER OUT OF AN INITIAL GAS CLOUD
EXISTING SUN ACQUIRES PLANETARY MATERIAL FROM INTERSTELLAR SPACE
EXISTING SUN ACQUIRES PLANETARY MATERIAL EITHER FROM ANOTHER STAR OR BY HAVING MATERIAL PULLED OUT OF ITSELF

| | |
|---|---|
| DESCARTES | 1644 |
| KANT | 1755 |
| LAPLACE | 1796 |
| VON WEIZSACKER | 1944 |
| TER HAAR | 1950 |
| HOYLE | 1960 |
| MC CREA | 1960 |

| | |
|---|---|
| BERLAGE | 1932 |
| ALFVEN | 1942 |
| SCHMIDT | 1944 |
| WOOLFSON | 1964 |

| | |
|---|---|
| CHAMBERLAIN | 1900 |
| JEANS-JEFFREYS | 1917 |
| LYTTLETON | 1936 |
| HOYLE | 1944 |

Figure 1. Solar system cosmologies.

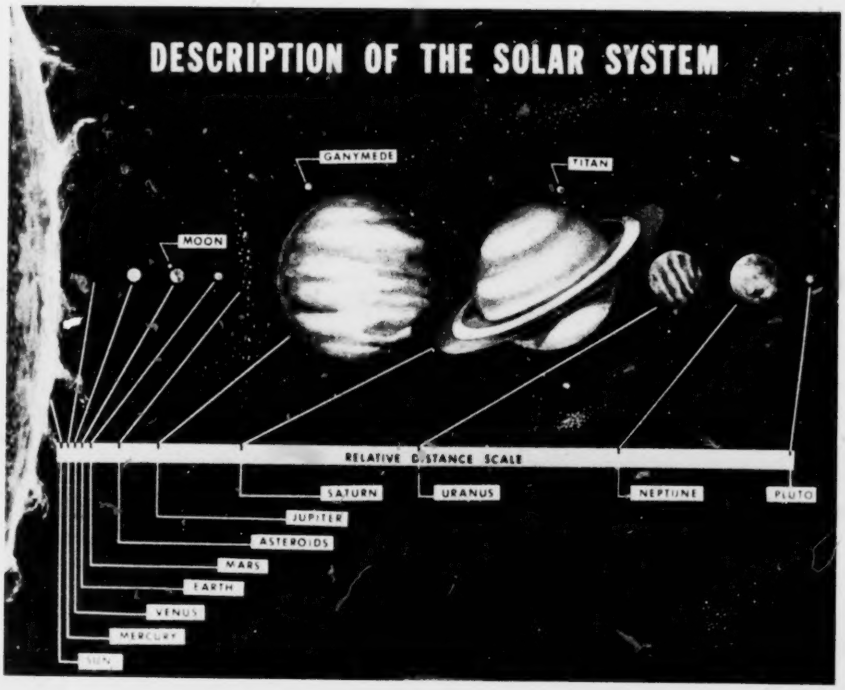

DESCRIPTION OF THE SOLAR SYSTEM
GANYMEDE
TITAN
MOON
RELATIVE DISTANCE SCALE
SATURN
URANUS
NEPTUNE
PLUTO
JUPITER
ASTEROIDS
MARS
EARTH
VENUS
MERCURY
SUN

Figure 2. Description of the solar system.

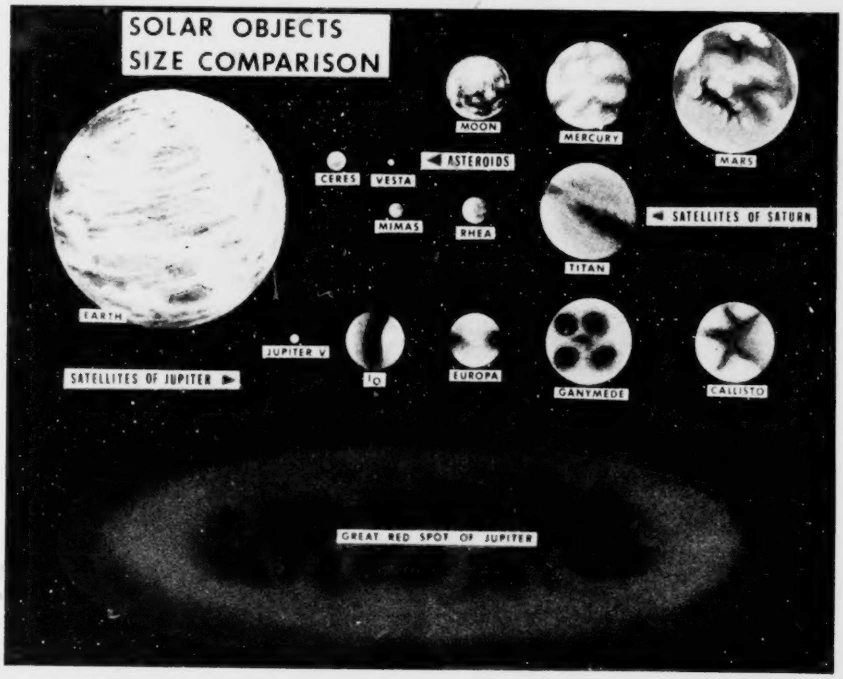

SOLAR OBJECTS
SIZE COMPARISON
MOON
MERCURY
MARS
CERES
VESTA
◄ ASTEROIDS
MIMAS
RHEA
TITAN
◄ SATELLITES OF SATURN
EARTH
JUPITER V
IO
EUROPA
GANYMEDE
CALLISTO
SATELLITES OF JUPITER ►
GREAT RED SPOT OF JUPITER

Figure 3. Solar objects size comparison.

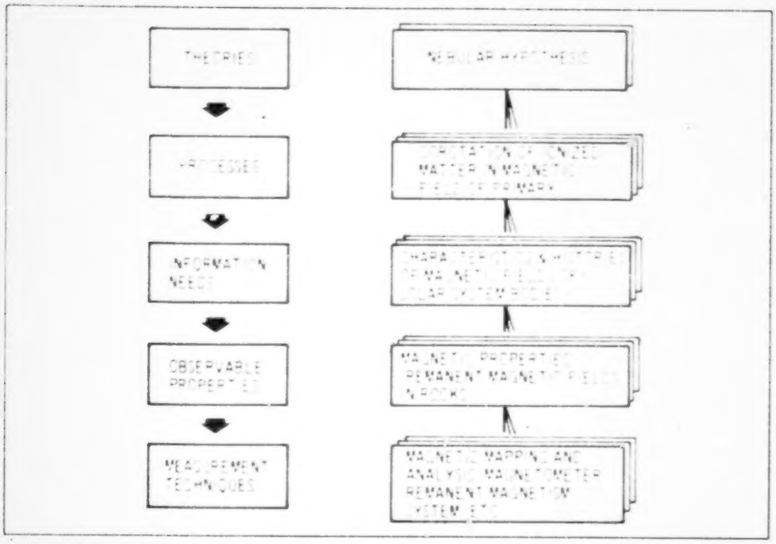

THEORIES
PROCESSES
INFORMATION NEEDS
OBSERVABLE PROPERTIES
MEASUREMENT TECHNIQUES
NEBULAR HYPOTHESIS
[illegible] OF IONIZED MATTER IN MAGNETIC FIELD OF PRIMARY
CHARACTERISTICS AND HISTORIES OF MAGNETIC FIELDS OF SOLAR SYSTEM BODIES
MAGNETIC PROPERTIES: REMANENT MAGNETIC FIELDS IN ROCKS
MAGNETIC MAPPING AND ANALYSIS: MAGNETOMETER REMANENT MAGNETISM SYSTEM, ETC.

Figure 4. Space exploration rationale development.

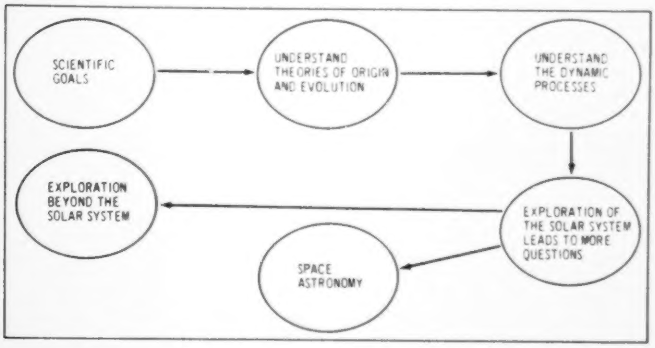

SCIENTIFIC GOALS
UNDERSTAND THEORIES OF ORIGIN AND EVOLUTION
UNDERSTAND THE DYNAMIC PROCESSES
EXPLORATION OF THE SOLAR SYSTEM LEADS TO MORE QUESTIONS
EXPLORATION BEYOND THE SOLAR SYSTEM
SPACE ASTRONOMY

Figure 5. Relationship of scientific goals to space astronomy [7].

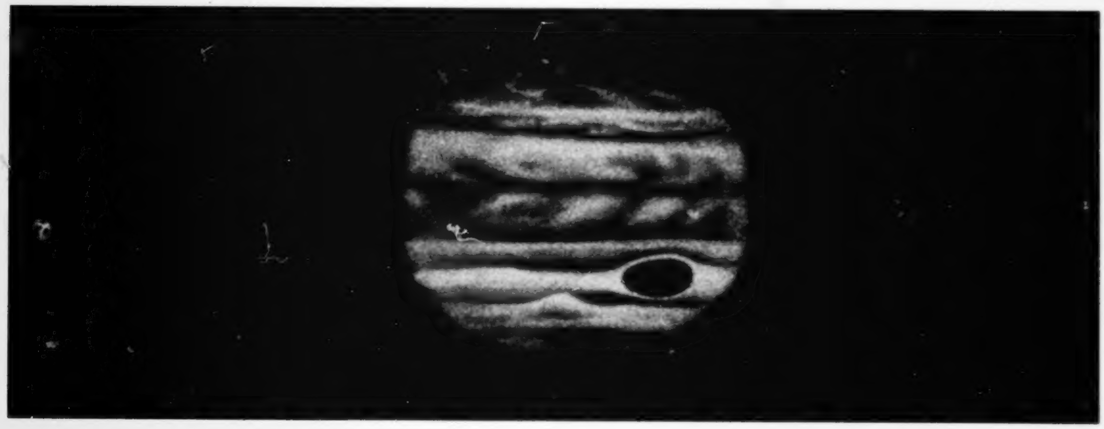


Figure 6. Planet Jupiter with its four moons.

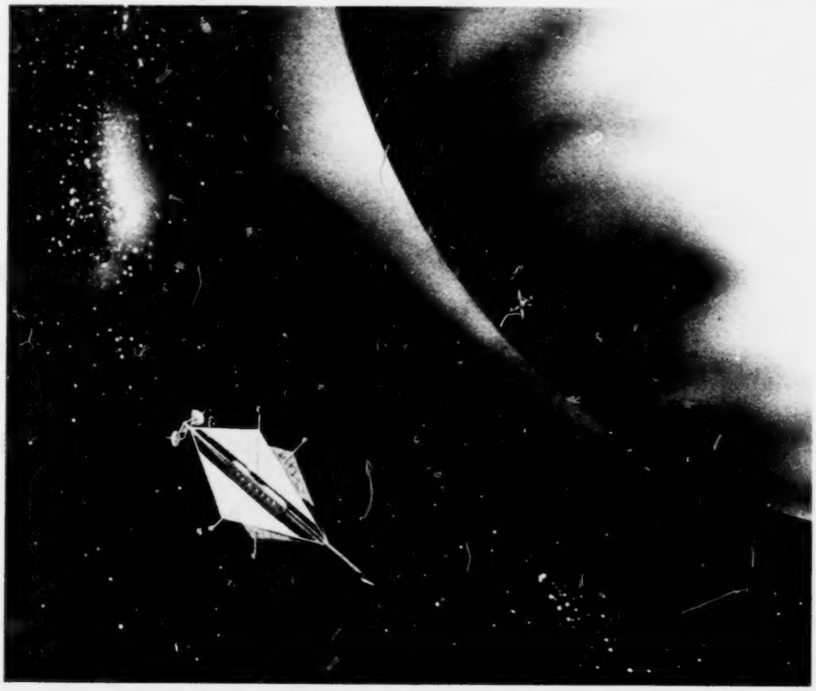


Figure 7. Exploration of Jupiter.

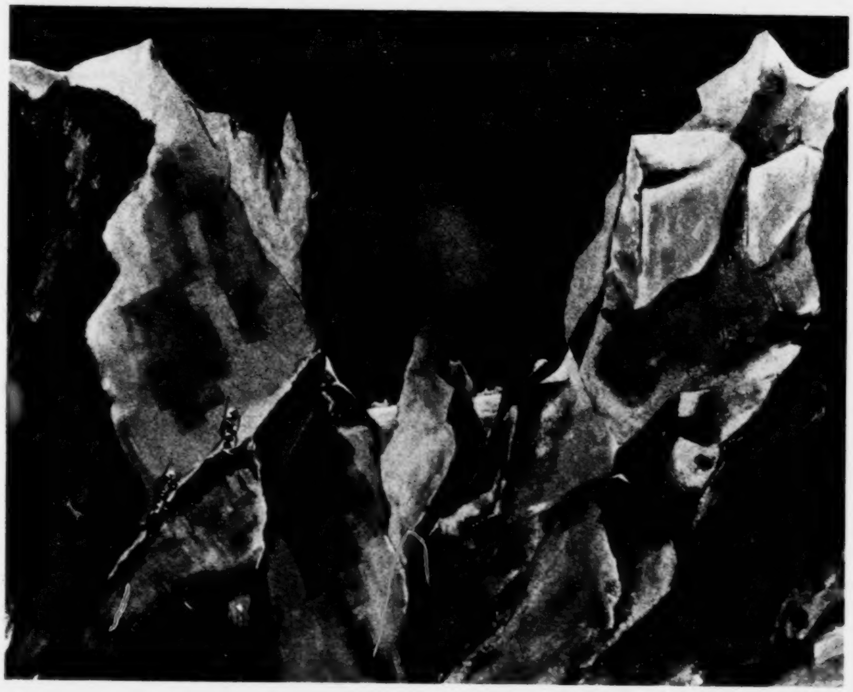


Figure 8. Manned exploration of Jupiter's moon, Ganymede.

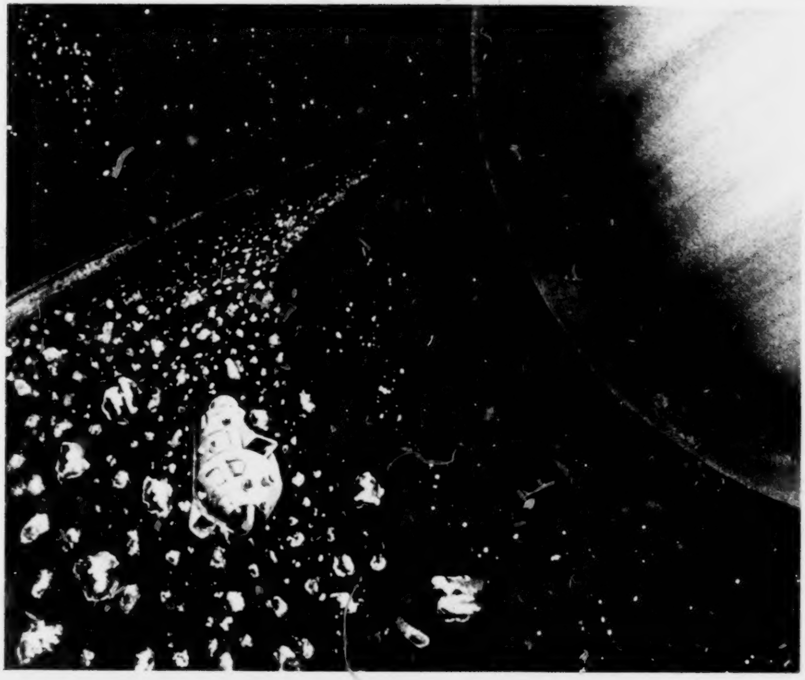


Figure 9. Exploration of the rings of Saturn.

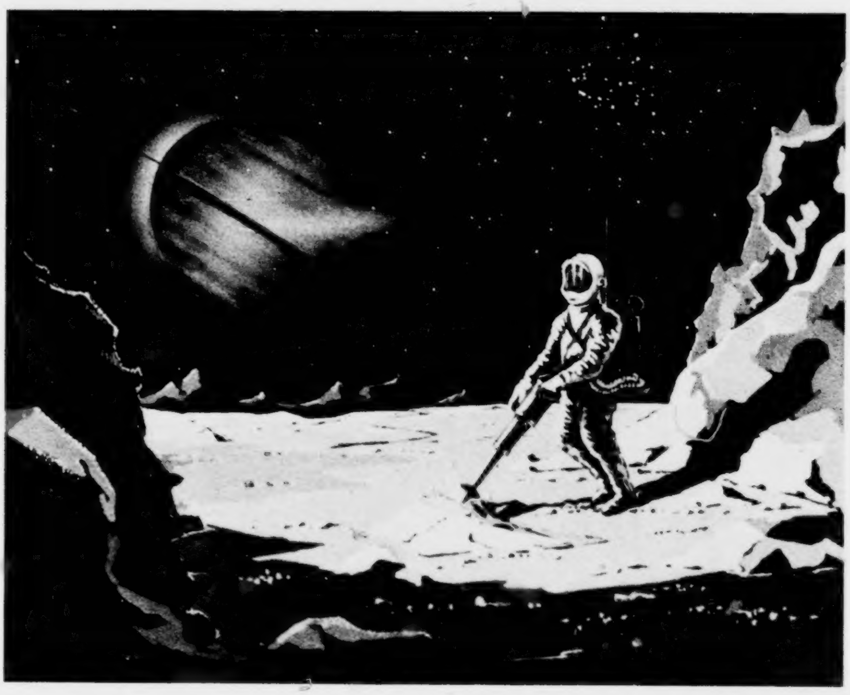


Figure 10. Manned exploration of Saturn's moon, Titan.

# SESSION VII
# SPACE MANUFACTURING BENEFITS

# STATUS AND PLANS OF NASA'S MATERIALS SCIENCE AND MANUFACTURING IN SPACE (MS/MS) PROGRAM

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## Abstract

Following 2 years of relatively low-level exploratory work, the Materials Science and Manufacturing in Space program is now in a phase of expansion toward higher levels of effort. The main thrust of this effort is toward initiation of a research and development program on the Space Shuttle missions that can prepare the way for possible commercial manufacturing operations on permanently orbiting space stations. Experiment capabilities, currently being planned for the Space Shuttle, will be based on an inventory of reusable general-purpose equipment that can be configured in many different ways to meet individual experiment requirements. It is expected that this approach can support very large numbers of experiments and make flight opportunities accessible to many potential experimenters, who would not be prepared to involve themselves in the development of flight hardware.

## Introduction

For ages man has dreamed of space as a new ocean to convey him out beyond the earth to the moon, the planets, and ultimately the stars. It is interesting to note that the spacecraft in these dreams were thought of only in terms of transportation. The spacecraft described by Jules Verne in "Journey to the Moon" and the ones used by Buck Rogers in his fascinating adventures were for travel in space. It is only recently we have begun to realize that orbiting spacecraft can provide other very important benefits for use right here on earth. Through use of spacecraft as an observation platform, many practical applications for space have evolved. They include such areas as meteorology, navigation, communications, and earth resources — to name a few.

Fairly recently, NASA has begun to explore a completely new field of applications, making use of properties of space to produce products impossible or prohibitively difficult to make otherwise. This new program had its genesis at the Marshall Space Flight Center (MSFC) where a few farsighted people began to discuss the possibilities of this new field of space applications with representatives of industrial organizations. Based on these contacts, two symposia were held at MSFC in 1968 and 1969 in which industrial concerns were invited to present ideas for using space for materials processing and manufacturing in space. Participation was excellent. Representatives of over 60 companies and research organizations attended, and 40 technical papers were presented at these two meetings.

With this encouraging beginning NASA started a program of research to build a technology base and explore promising possibilities for space research. This has grown from a limited effort of a few hundred thousand dollars in 1968, to a fairly subtantial research and development activity involving a number of industrial and research organizations, with funding in excess of $1 million per year.

## Program Status

The results of these activities to date have convinced us that manufacturing in space is technically feasible and that space research in material science and technology is likely to pay off. As shown in Figure 1, one form of payoff can be expected in terms of useful scientific knowledge derived from space research, which improves our technological capability on the ground. This is likely to be the area from which benefits are initially derived and indeed may be the area of greatest long-term benefit as well. Eventually, however, we also expect returns in terms of products produced in space for market here on earth. Should they materialize, these returns will be very direct and tangible, because they will come in the form of profits on sales.

If we are to take space manufacturing seriously as a goal, we are forced to contemplate some grandiose objectives. The whole proposition makes economic sense only if we succeed in creating a space-manufacturing technology that can operate at a profit and if manufacturing operations go on long enough and reach a scale large enough to recover the investment that went in to making them possible. Obviously these are ultimate objectives rather than near-term ones. Our immediate goals are threefold, as outlined in Figure 2.

Extensive ground research is needed to understand the potential applications of weightlessness and other features of space well enough to know where the payoffs are. Therefore, an active and diverse program of in-house and contracted research is needed to build our technology base and identify promising processes for in-flight studies. Concurrent engineering development effort is also needed to define experiment techniques and flight facilities in which to conduct our space experimentation.

Our second goal is to expand the involvement of the scientific and industrial community at large. These are the ultimate users of our space capability and provide the best source of ideas for eventual utilization of space to solve their problems.

Finally, since the benefits of null gravity can only be realized in space, major program emphasis must be directed toward maximum utilization of spaceflight opportunities.

Since the thrust of our immediate effort is aimed toward meeting these goals, we will explore in more detail our current activities and future plans in each of these areas.

## Buildup of the Technology Base

Recognizing the need for a sound technological base to underpin our future flight effort, the major emphasis of our present program is aimed at building this base. As previously mentioned, funding for this activity is now well in excess of $1 million per year and involves a number of in-house and contracted efforts (Fig. 3). The program is managed almost entirely from MSFC and is supporting contract studies in 17 outside organizations from a variety of different fields and interests. Eight tasks also are underway in-house at MSFC. It should be noted that nine additional tasks have been proposed for which support could not be provided.

As a result of our study effort so far, a number of promising areas have been identified, which eventually may prove economically attractive. Some of the most promising prospects are listed in Figure 4.

The possibility of levitating solids and liquids is one of the most obvious applications of weightlessness. Suspension of materials free of physical contact of containers should permit the production of ultrapure metals and crystals. New types of glasses could be produced by cooling molten oxides into the glassy state without external disturbances that nucleate unwanted crystalline grain growth. Semiconductor crystals might be shaped directly from the melt into forms ready for use.

The lack of buoyancy should allow us to maintain a very homogeneous mixture of substances of varying density. This would prove highly beneficial in the production of such products as foamed metals, metal composites, and electrophoretic separation of large organic molecules in buffer solutions.

The most sophisticated source of control over space processes lies in the fact that heat and mass transport in liquids and gases will be predictable and controllable when the complicating influence of convection is suppressed. This has particular application in growth of large single crystals of high purity. It should also prove useful in the development of unique and useful new structures in two-phase alloys, such as eutectic and monotectic systems and in making specialized optical components free from defects that limit their performance.

These are only a few examples thought of in the earliest stages of the program without any data from actual space experiments. Considerably more research is needed to ascertain the real potential of these new possibilities. Furthermore, as we continue our studies, many new ideas will become apparent that should be pursued.

Our current research effort has a twofold purpose, as shown in Figure 5. The major portion of our study activity is aimed toward expanding our understanding of the potential to be derived from space processes in these promising areas of materials processing. The studies also point up the requirements and capabilities that must be provided by our experimental facilities in space. Based on these requirements, a second element of our study activity is directed toward evolving apparatus technology and experimental techniques needed for development of an experiment facility in space which can support large numbers of experiments with varying needs. A few studies also have been undertaken to better establish user interest and examine the economic potential of some of the more promising processes.

Looking ahead, I would expect our support of the basic technology effort to begin leveling off. However, as new ideas develop, work in these new areas will be emphasized. If we look at Figure 5, we see that most of our technology effort to date has been directed toward crystal growth and metallurgy. As our base of interest is broadened, new concepts and ideas should be identified with need support.

The second immediate goal of the program is to broaden our base of interest both internally and externally. The expertise and support of other NASA centers is needed to develop the full potential of materials processing and manufacturing in space. Similarly, the involvement of outside organizations needs to be expanded.

## Expanded User Involvement

Referring to Figure 5, we find that approximately 20 organizations are actively involved in the Materials Science and Manufacturing in Space program. Furthermore, while it is not readily apparent from Figure 5, the majority of these groups are aerospace or space-related organizations. A much broader base of involvement is needed, particularly from the nonaerospace research and industrial community, and some preliminary surveys indicate that interest exists among these potential users.

Following the Space Station Utilization Conference, held last year at the Ames Research Center, some 20 nonaerospace research, development and manufacturing organizations completed questionnaires expressing interest in this applications area. A similar survey of European companies and research labs in eight countries drew 76 responses of positive interest in the Materials Science and Manufacturing in Space program. These results are highly encouraging.

A number of measures are being pursued to capitalize on this interest (Fig. 6). The program plans to create more user awareness and provide more avenues for user participation through:

1. Increased contact with the user community to determine their needs and acquaint them with the possibilities of space research to solve their problems.

2. More possibilities for user participation through open procurement, thereby stimulating a diversity of ideas through the competitive process.

3. Increased opportunities for companies to conduct space research by taking maximum advantage of flight opportunities of current and planned flight programs. This will be discussed in more detail later in the paper.

4. Persistent missionary work at technical symposia, laboratory colloquia, technical society meetings, etc., to acquaint the user community of the available possibilities for space research in materials processes.

5. Development of a fair and workable approach to the commercial users of space that avoids unwarranted advantages and yet offers commercial incentives by protection of proprietary rights. Although no formal policy has been established as yet, our objective is to encourage private utilization of our space capability. To this end, we would adopt a policy as liberal as possible and consistent with public interest in accommodating industrial involvement. Specific arrangements will be worked out on a case-by-case basis.

## Flight Opportunities

So far we have discussed only the ground-based activities which support the Materials Science and Manufacturing in Space program. However, by its nature, this program requires the space environment to exploit the effects of null gravity on materials processes and product characteristics. Furthermore, the kind of special attention and close control required to conduct the kind of experimentation planned in space makes the program best suited for manned space missions. Consequently, the experiment program is being developed for manned flight.

The Apollo program offers the only manned space flight possibilities for the next few years. Since the primary objective of Apollo is lunar exploration, it affords very little opportunity for other areas of experimentation. However, Apollo missions do sometimes have enough residual resources to accommodate small, self-contained experiment packages intended for operation on a noninterference basis, making use of residual mission resources during the earth-moon drift phase. Several simple demonstrations of techniques and concepts of basic importance to design of later experiments have been developed to take advantage of this capability. They include (Fig. 7) a sensitive test for any convection effects that may exist at very low force levels, a feasibility test of electrophoretic separation in a liquid medium and a study of composite casting, and crystal growth metals solidification of low temperature materials in null gravity. These demonstrations were initially conducted on Apollo XIV with varied success, and reports on the results will become available in the near future. Improved versions of these demonstrations, building on Apollo XIV experience, are now under development for flight, hopefully on Apollo XVI and/or XVII.

A more ambitious experiment program is being implemented for the Skylab program scheduled for 1973. During the development of experiments for the Skylab, it became evident that experiments for manned missions can be built more cheaply and easily if they can be performed in an existing general-purpose facility. Therefore, a specialized facility is being developed for Skylab with the versatility to accommodate a variety of materials science investigations selected for flight. This facility contains a spherical vacuum chamber to house the experiments, an electron beam unit for sample heating, and a control panel to control experiment activities. Other services, such as water, spacecraft power and motion picture coverage, are also available.

Five experiments related to the program are currently approved for flight on Skylab (Fig. 8). They consist of metallurgical experiments to study the effects of reduced gravity on solidification, grain structure and mechanical properties of metals and composites, and the growth of a single gallium arsenide crystal by solution transport.

Although this experiment program on Skylab is quite limited, it does provide an early opportunity to gain experience in the development and integration of individual experiments into a common facility. This experience is particularly valuable as we plan our experiment program for the Shuttle.

With relatively simple modifications to the M512 facility, the experiment complement of the Materials Science program on Skylab could be significantly expanded. Two modifications which are being considered include the addition of a multipurpose electric furnace and an electromagentic positioning system for levitating samples. With these additions, a large number of samples of alloys, composites, and crystalline materials could be accommodated from the industrial community for minimum cost and complexity.

Another possibility includes the addition of a carry-on-type electrophoretic separator, designed to be reloadable in flight. Hence a large number of biological samples could be carried to orbit, separated, collected, and returned to earth for analysis.

Even though these possibilities look attractive, it must be remembered that changes to Skylab hardware at this late date are very difficult, and the feasibility of these modifications is quite uncertain. However, there are several other potential mission prospects in the interval between Skylab and the Shuttle. These include a possible second Skylab mission and/or one or more Command and Service Module (CSM) flights. Planning in the material science area to take advantage of these possibilities is underway including incorporation of the modified M512 facility described above.

Although we expect useful results from our Apollo and Skylab missions, our first opportunity for research and development work, on the scale needed to generate ultimate applications, will come with the Space Shuttle. For the Space Shuttle missions NASA plans to provide a relatively large inventory of modular, general-purpose lab equipment that can be configured flexibly to match experiment requirements and spacecraft resources on any mission where space is available. One concept for a Materials Science and Manufacturing in Space Laboratory to be used with the Shuttle is shown on Figure 9. As envisioned in this concept the equipment would include a "core" instrumentation and control rack to provide general support on any mission. Special-purpose modules could then be added to meet the particular experiment requirements of a mission. These special-purpose modules would include vacuum chambers, furnaces, levitation apparatus, biological processing equipment, fluid-handling facilities, etc. Each of these major components would be backed up by an inventory of subassemblies that could be flown repeatedly in many different combinations as experiment requirements dictate. By reuse of this basic equipment, program cost can be substantially reduced.

Through this approach we hope to simplify interfaces between the experiment and spacecraft, and reduce cost and lead time for experiment development. Experiments generally will only be called upon to supply samples and instructions for processing them in NASA's payload apparatus. Thus large numbers of users can be accommodated at modest cost and a minimum lead time — on the order of weeks to months from acceptance to flight, instead of 3 to 5 years required in current programs.

## Long-Range Program Prospects

During the early period of Shuttle operation, experimentation would be limited to short-duration missions (7 to 30 days), carried out within a module which remains attached to the Shuttle. In this period, the program emphasis will be on research experiments which provide information useful to our ground technology, as well as those that build up our understanding of processes in weightless media, which eventually may provide an economic payoff.

When permanently orbiting space stations begin to be available, research will continue, using apparatus that will have evolved from the Shuttle payload inventory, but development work will also begin on a few of the processes that seem most promising at the time. It is hoped that some of these processes will be ready for pilot-scale manufacturing operations as soon as the Space Station complex can support this level of activity, and that a few of them will reach full-scale commercial manufacturing status in the latter part of this century. By the turn of the century, space manufacturing may account for a significant fraction of all space operations, and thereafter it is likely to play a large role in assuring a permanent future for space flight because of the essential functions it will perform in some parts of the world's economic activity.

- AN APPLICATIONS PROGRAM THAT SEEKS TO DELIVER CONCRETE ECONOMIC BENEFITS FROM MANNED SPACE FLIGHT:
  - INDIRECT BENEFITS FROM RESEARCH RESULTS THAT EXPAND KNOWLEDGE OF MATERIALS
  - DIRECT BENEFITS FROM CREATION OF NEW PRODUCTS OR IMPROVEMENTS TO EXISTING ONES

Figure 1. Materials science and manufacturing in space.

- BUILD–UP OF THE TECHNOLOGY BASE
  - PROCESS R & D
  - ENGINEERING DEVELOPMENT
- EXPANDED USER INVOLVEMENT
- MAXIMUM UTILIZATION OF EXISTING FLIGHT OPPORTUNITIES

Figure 2. Immediate program goals.

| TYPE OF ORGANIZATION | ACTIVELY SUPPORTED | SUPPORT SOLICITED |
|---|---|---|
| AERO SPACE AND DEFENSE | 5 | 4 |
| R&D COMPANIES | 1 | 4 |
| UNIVERSITIES | 5 | |
| COMMERCIAL ORGANIZATIONS | 4 | 1 |
| OTHER GOVERNMENT AGENCIES | 2 | |

Figure 3. Organizations involved.

- CRYSTAL GROWTH
  - CRYSTAL GROWTH FROM CONVECTIONLESS SOLUTIONS & VAPORS
  - CRYSTAL GROWTH FROM MELT, SHAPED FOR FINAL USE
  - FLOATING ZONE REFINING
- METALLURGICAL PROCESSES
  - METAL MATRIX COMPOSITES
  - EUTECTIC & MONOTECTIC ALLOYS OF CONTROLLED STRUCTURES
  - FOAM CASTING
- BIOLOGICAL PREPARATIONS
  - ELECTROPHORETIC PURIFICATION OF VACCINES
  - INCUBATION PROCESSES FOR BIOLOGICALS
- GLASS PREPARATION & PROCESSING GLASSES
  - PRODUCED BY CONTAINERLESS SOLIDIFICATION
  - HI QUALITY LENSES FOR LASERS & OPTICAL INSTRUMENTS
- PHYSICAL PROCESSES IN FLUIDS
- CHEMICAL PROCESSES IN FLUIDS

Figure 4. Technical areas for potential exploitation.

| PROCESS R & D | CONTRACT | | IN-HOUSE | |
|---|---|---|---|---|
| | FY-71 | FY-72 | FY-71 | FY-72 |
| CRYSTAL GROWTH | 5 | 7 | 2 | 2 |
| METALLURGICAL PROCESSES | 4 | 6 | | |
| BIOLOGICAL PREPARATIONS | 2 | 3 | | |
| GLASS PROCESSING | 1 | 1 | | |
| PHYSICAL PROCESSES IN FLUIDS | 1 | 2 | | |
| CHEMICAL PROCESSES IN FLUIDS | | | 1 | 1 |
| ENGINEERING DEVELOPMENT | | | | |
| FACILITIES DEFINITION | 3 | 6 | 2 | 2 |
| LABORATORY CONCEPTS | | 1 | | |
| USER INTEREST | 2 | | | |

Figure 5. Current program structure.

- DIRECT NASA/USER CONTACT
- OPEN COMPETITION FOR CONTRACT WORK
- MAXIMIZE OPPORTUNITIES FOR FLIGHT RESEARCH
- SYMPOSIA & TECHNICAL MEETINGS
- PROTECTION OF USER INTEREST

Figure 6. Expansion of user involvement.

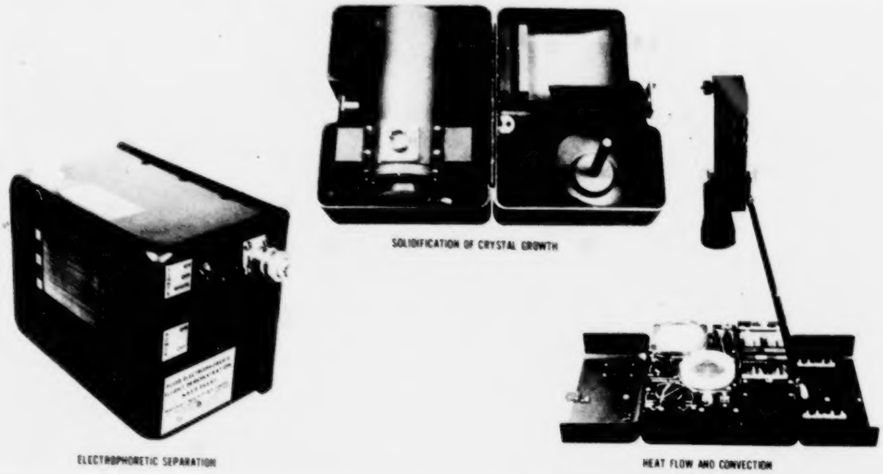
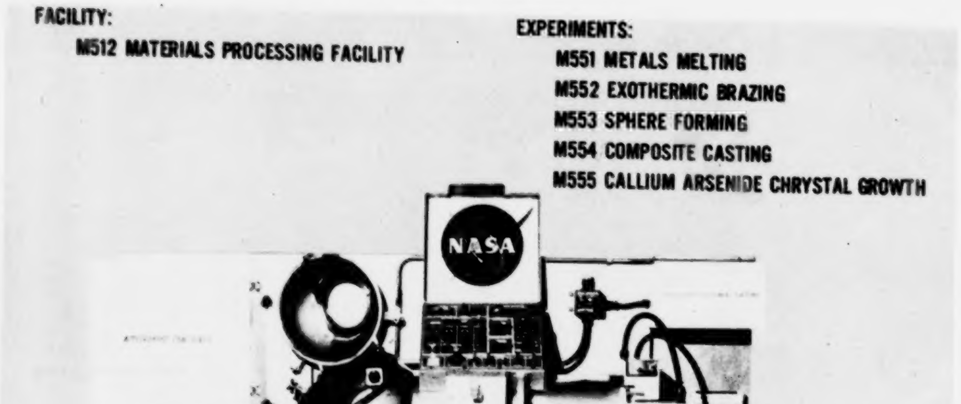

SOLIDIFICATION OF CRYSTAL GROWTH
ELECTROPHORETIC SEPARATION
HEAT FLOW AND CONVECTION

Figure 7. Apollo demonstrations.


FACILITY:
M512 MATERIALS PROCESSING FACILITY

EXPERIMENTS:
M551 METALS MELTING
M552 EXOTHERMIC BRAZING
M553 SPHERE FORMING
M554 COMPOSITE CASTING
M555 CALLIUM ARSENIDE CHRYSTAL GROWTH

Figure 8. Skylab apparatus.

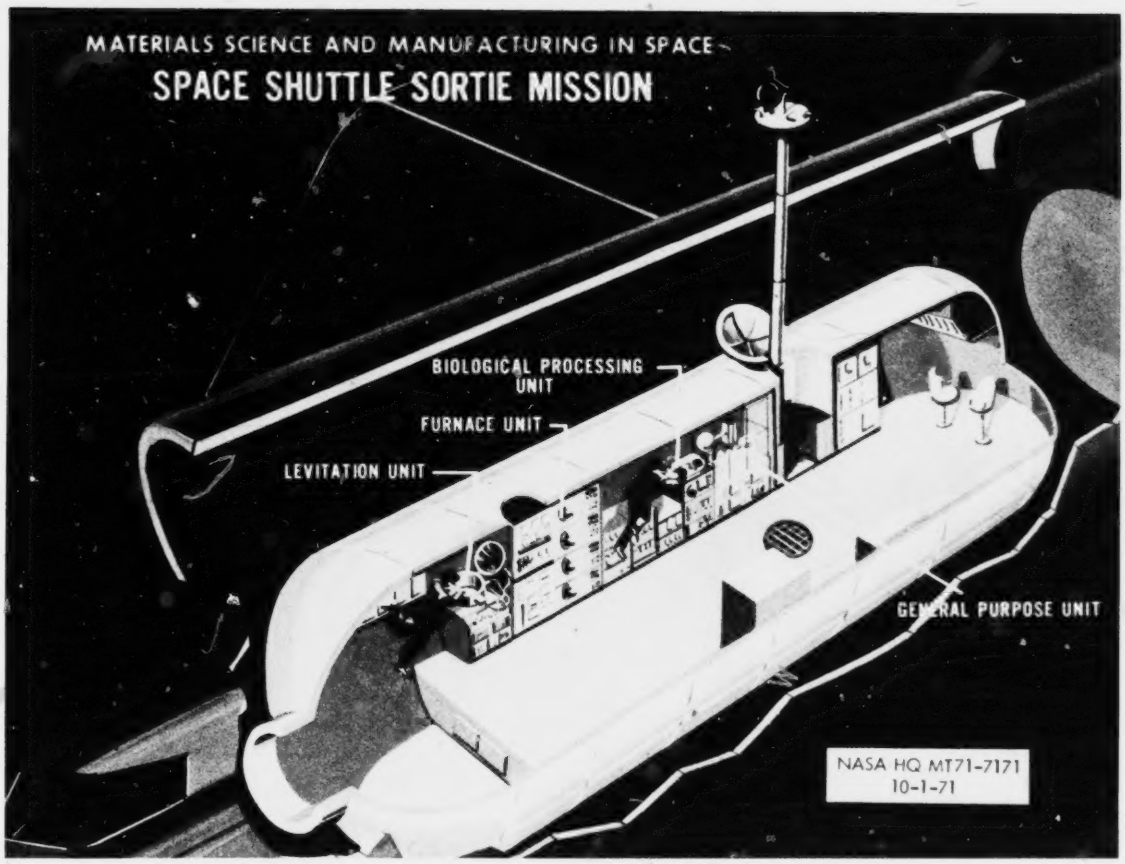

MATERIALS SCIENCE AND MANUFACTURING IN SPACE
SPACE SHUTTLE SORTIE MISSION
BIOLOGICAL PROCESSING UNIT
FURNACE UNIT
LEVITATION UNIT
GENERAL PURPOSE UNIT
NASA HQ MT71-7171
10-1-71

Figure 9. One concept for a Materials Science and Manufacturing in Space Laboratory.

# SPACE ENVIRONMENT – A NEW DIMENSION IN THE PREPARATION OF UNIQUE SOLIDS

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This report is about solids; primarily electronic solids, and what the absence of gravity in space can do in achieving homogeneity in materials that we can not achieve on earth. First, though, some remarks will be made regarding materials, in general, and solids, in particular.

Up to about 15 years ago, the materials were primarily a matter of art, of trial and error. Science was lagging behind. However, things have changed. Now, theoretical or scientific or fundamental predictions about devices, structures, and components are way ahead of materials technology. We speculate, in fact, we show, on sound basis, what we could do if materials were available; and during the last 10 or 15 years, nearly all of our expectations were realized, when the right materials were available. This is true even in the case of high-strength materials, the laser, semiconductor devices, and many of the other solid-state electronics.

The three parameters that worry us the most about materials are: first, structure – that is, how perfect the materials are in terms of having their atoms in the right places; two, purity – how pure they are; and, three, how homogeneous they are. In other words, what are the variations in purity and structural defects from one point of the material to the other? Two of these problems have come a long way in the last 15 years. Regarding structure, we can now prepare materials that are structurally perfect. Particularly in the electronic area, we can prepare silicon crystals and others which have absolutely no structural defects; all the atoms are where they should be. Regarding purity, we have achieved the purest materials as we know how to detect and identify. The purity in some of the electronic materials is in parts per trillion or better. However, we do not use very pure materials, for they are not good for very much. They must have impurities in them, but those impurities must be very carefully controlled and be extremely homogeneously distributed. Here is the stumbling block: how do I identify this type of heterogeneity? As we have been making progress in identifying them, we have been detecting more and more heterogeneities, which we can directly trace to gravity and which we can do nothing about on earth.

To be specific, you heard earlier that if one, on earth, is about to prepare a solid, he must use a liquid. One must first melt the solid for a solution by heating it. There is no way that one can avoid the heat convection which forms gradients – changes in temperatures. The heavier things tend to settle in the liquids or fluids, and the lighter things tend to rise. Why is that harmful? When these convections take place, the temperature changes at the places where you need perfect control, that is, between the solid and the melt. This means that the rate at which the solid is formed changes, and once that happens, there is absolutely nothing that you can do to make sure that that solid is going to be homogeneous. Why is that important? It is important on a microscale, for example, in the case of the ordinary casting of metals, of superalloys, which we need for high-temperature/high-strength applications, as in the case of jet engines and the like. There is a serious problem that has to do with gravity. As you cast a metal, the bottom part of the metal or the container is going to cool; so it solidifies, but in between that solid and the melt above it, there is an intermediate region where you have both solid and melt. As the solid solidifies, in many instances some of the lighter elements of that liquid are not incorporated into the solid, but are left behind in the melt. The melt becomes lighter directly above the solid and shoots up in jetlike form through the intermediate stage which is a mix of solid and liquid. This mixture then thins out and destroys the solid configuration and creates what people now call freckles or channels. These defects are very detrimental to the strength and other characteristics of materials.

Microscopic convection becomes of paramount importance in the electronic materials, the semiconductors. These devices are becoming smaller and smaller by the year. In the so-called integrated circuit, we assemble hundreds of devices the size of the order of microns. You can barely see them with the naked eye. This implies that on a wafer – a piece of silicon 0.75 in. diam by 1 in., there are about 1 million devices. You have to make sure that all of these devices are of materials which have the same characteristics on the microscale, to do this.

This is possible, but only with a very small yield today, and it is believed that the limit is here, not in terms of what we could do, but in terms of what we can do now. A very large computer on a good-sized missile will have 2000 individual integrated circuits, which means that about 20, 30, or 40 thousand devices can be accommodated in approximately 2 g of silicon. However, the end is not here. We have a number of devices waiting on paper and proven on fundamental grounds which we cannot produce, because the requirements on the homogeneity are even greater than today's. High sensitivity detectors, for instance, which require very high controlled impurity distribution, cannot be produced today. There are instances where we require very high concentration on what we want to put into the material; but, in order to do that, we require very high thermal gradients in the metal from which we grow it. In simple terms, this means that we have to impose on the liquid very high thermal gradients, which are impossible to maintain on earth.

What can be done on a microscale in space actually – not on a speculative basis? If we take a crystal of silicon and look at the outside, it looks very heterogeneous, not at all uniform. You see striations and heterogeneity. But out of that crystal, we must take sections to prepare the integrated circuit I was referring to before. Thus, it is no wonder that the yield of some of these devices is extremely small today.

Let us open up the crystal now and look further into it. Under higher magnification we would see the striations become very pronounced. If we magnify further to 1000 times, we would see that between the lines of striation there are many, many finer lines. Thus, at about 7 $\mu$m resolution you see many, many lines in between two striations; these are strictly the results of convections that take place at the interface and, in no way, can be completely avoided.

What can we really do to understand, here on earth, that indeed these heterogeneities are due to this type convection; that is, they are because of the fact that the crystal or solid does not solidify at the same rate throughout? It is not easy to prove this, but it has been done recently. To illustrate the principle, consider a tree. If you cut a tree across and look at the trunk, the rings represent the number of years that the tree has lived. Now, if two rings are far apart, you know that the tree grew faster than in the year where the two rings are close together. That is, we have time markers here to tell us how fast or how slow the tree was growing. We can do the same thing with the crystal. We put vibrations in it, and these vibrations would be the equivalent of the rings of the years in the tree's life. And those vibrations are of constant frequencies, a year each, although it happens to be seconds. The separation of the rings of vibration is not constant; where we cannot even tell them apart, the crystals were growing very, very slowly and where they are farther apart, the crystal grew faster. We see that the rate of growth of the crystal is not really uniform, and, in fact, it changes very drastically.

Is there anything here on earth that we can do to improve this? Yes. We can decrease the convection current in two ways. One, we can turn the melt around and heat it on the top, not on the bottom; that means, from the bottom up, or you grow your crystal upside down. We certainly have done this, but you can appreciate the fact that you only can do it as a laboratory curiosity, that you cannot turn things upside down, and even then, note, you do not completely eliminate the convection configuration, only to some extent. The second method is by using a magnetic field. Most metal melts will behave like a viscous liquid if you put them in a transverse magnetic field, that is, the viscosity increases and they will be less subjected to convective currents. We have done that very simply by putting our apparatus into a magnet. If the temperature is low, we can now achieve what we would expect to achieve when there was no gravity. We achieve complete homogeneity. Why do we not do that rather than go to space? Because we are very limited, in terms of size, in terms of materials, and in terms of temperature. We achieve good results only at low temperatures. If we go up in temperature, even the magnetic fields cannot do us very much good. They can change things but cannot eliminate the problems.

What can we expect to achieve then in space? I would like to believe that, in this particular area, one need not speculate. Once there is no gravity, there will be no convection, and there will be homogeneity. But what do we do with homogeneous materials? Do we just improve the yields of the things that we can do now? The answer is No. We will increase the density of what we can do now by a large factor, but more important, we will be able to put to use theoretical schemes of devices for higher power, higher sensitivity, smaller sizes, and including devices which are so badly needed in the biological sciences, for either detection of pressure fluctuations in bloodstreams, temperature flucuations in bloodstreams, or things of that nature; not to mention the impacts of high-temperature semiconductors, like silicon carbide, zinc sulfide, zinc oxide, or exotic types of semiconductors. These exotic types are so difficult to prepare at all, in any applicable form on earth, we are today sort of bypassing them or are ignoring them outright.

I hope this report has conveyed to you some of the reasons that make us look to space, to the use of space as a truly new dimension in making materials which we can now only play with on paper. Having homogeneous materials does not have to do just with meeting the great expectations which are based on sound scientific and engineering basis. Beyond that, I believe, the implications of this type of homogeneous materials would even surpass the most far-out science-fiction imagination today.

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# SPACE PROCESSING - A PROJECTION

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This paper contains estimates concerning space manufacturing, which might well become the largest and most specific application of space technology by the end of the century. It does not say, however, that these projections will happen, only that they can happen if nurtured and developed. The plan for nurturing and developing space manufacturing is very preliminary, although more detailed plans for some small-scale research and development activities have been drafted.

Recent analysis [1] of various ideas for space manufacturing indicates technical benefits which may result from preparing many materials and products in space. All of these ideas merit further exploration. At this time, however, two classes of materials do appear to satisfy the technical and economic constraints that must be considered before actual space manufacturing can be seriously contemplated. These two classes of materials and some products are:

1. Electronic crystals
    a. Float-zone-refined semiconductors
    b. Solution-grown crystals,
2. Biologicals
    a. Vaccines for human usage
    b. Cells for human usage
    c. Viral insecticides and pesticides.

We estimate that some 30-50 Space Shuttle payloads might be generated from these product areas by the end of the century. The total value of a payload with this type of product could range from $10 million to $1.5 billion. However, some of this value would be attributed to ground-based pre- and postflight operations. More detailed estimates are shown in Table 1. In addition, several more payloads may be required to provide logistic support as well as the several research and development (R&D) payloads that will be needed before actual manufacturing can proceed.

Each of these products is briefly described and the production calculation outlined in the following pages. Many details might refine the calculations and even greatly change the products or quantities, but we strongly feel that other products in other quantities will replace them. We firmly believe this because the basis for space manufacturing ideas is using the zero gravity, which is available only in space. As long as we have gravity, we will have some of its detrimental effects when we process materials on earth. So the basic idea of space manufacturing is both simple and elegant, but much R&D will be needed to prove the ideas and to plan the experiments and missions in detail.

## Electronic Crystals

### Float-Zone-Refined (FZR) Semiconductors

Small boules of silicon (1.5-2 in. diam). Present applications for float-zone-refined silicon range from integrated circuits to rectifiers, diodes, and similar electronic devices. Space processing of this material would primarily be warranted for the economies of making larger diameter boules and/or wafers from them. Such boules or wafers might be diced into smaller pieces and more efficiently handled in manufacturing other items. Devices based on this single-crystal silicon are now valued at $1.3 billion in the U.S. and $2 billion worldwide, with a predicted increase to $2 and $3 billion respectively by 1980 [2]. Additional processing in space (if warranted technically and economically, such as by wire or ribbon drawing [3] or by using the space vacuum in vapor depositing films) would shift some of this potential market toward the space transportation business. Current production is about 28 tons per year in the U.S. and 45 tons total worldwide. This material is valued at about $450 per pound or $40 million worldwide.

## Large Silicon Boules and Wafers (4-8 in. diam)

Float-zone-refining in space is the only apparent way to make large boules and wafers of high quality [4].

If these sizes were available, it would be more feasible to consider solid state control and direct current power transmission, enabling underground installation in densely populated areas, overhead installation from remote generating facilities, and as interties among systems. Since solid state rectifiers and other distribution and conversion equipment are highly reliable and more easily serviced, such equipment could easily boom into a tremendous market that would quite clearly depend upon large-diameter silicon.

A Federal Power Commission engineer [5] has reported estimates that in the U.S. alone, within two decades, there will be about 350 new generating plants needed to produce another million megawatts of electrical energy. This will require about 400 000 miles of high voltage transmission lines. These additional transmission lines are expected to require up to 4 million acres of land for right-of-way, beyond our present usage of 4 million acres. While these right-of-way acres potentially are also usable for industrial or commercial purposes, they are presently inefficiently used for these secondary purposes. In any case, the overhead right-of-way in densely populated areas is rapidly becoming so expensive that more cable is likely to go underground for the last 20-40 miles into a city [6]. Although this move to underground power cables generally costs about five times as much as overhead lines, applying cryogenic (low temperature) technology or perhaps even superconductor (ultralow temperature) technology may overcome this cost disadvantage. Such cables might require the purity and perfection that zone refining and space processing can probably provide; however, this is not sufficiently certain to warrant inclusion in this forecast. Therefore, only the related distribution equipment is included.

This expected trend toward High Voltage Direct Current (HVDC) [7] energy transmission and the related use of solid state conversion and distribution equipment would require many tons of semiconductors, such as silicon. Assuming that only half of the new distribution network were operated on direct current, but that a large number of substations and customized power conditioning equipment would also need solid state equipment, it is estimated that semiconductor requirements could total 200 to 400 tons per year for these applications. We have used the lower figure in our estimates.

Near zero gravity processing in space might achieve a potential refinement of these estimates, because of a process improvement of great significance to the semiconductor, as well as to some related fields. This would be the drawing of wires and controlled-thickness ribbons directly from the melt. Although extensively studied, this operation is not possible on earth in the case of materials having sharp melting points [3]. If this then were accomplished in space, it could markedly increase the yield of silicon from boules into devices, thereby reducing the total requirements. It could also permit preparing the FZR boules here on earth, and only require space processing for the ribbon drawing. This would not change the weight of material to process, but would probably simplify the space processing operations.

Other Single-Crystal Electronic Materials [8]. Although silicon and germanium account for nearly 90 percent of the electronic single-crystal materials production, several other materials are used in single-crystal form in electronic devices and have an even higher value per pound than silicon. Such materials currently average $5000-10 000 per pound. They could account for about 5 tons now, and could increase to 10 tons by 1980, if one extrapolates the present rate of growth. However, the "technical action" for new electronic materials is in this field. It is therefore quite possible that the field could grow to the point of equaling the present production of float-zone-refined silicon or about 50 tons per year of materials. This would then lead to a potential of $80-100 million.

## Biologicals

Many feel that higher purity biologicals are generally desirable and urgently required in some specific cases [9, 10, 11]. The higher purity is required to reduce undesirable side effects and to permit applying stronger, more effective doses [9]. This had been demonstrated here on earth in the case of the Hong Kong flu vaccine [12], but it appears possible to further improve this product significantly through space processing.

Basically, the idea of space processing the three classes of biological products discussed in this section would be to purify them primarily by fluid electrophoresis. This process is nearly unusable for large-scale preparative work here on earth because of convection and sedimentation problems. On a very small scale as an analytical technique, however, it is unsurpassed and is, therefore, widely used. We have concentrated on this process, although space processing of biologicals may also require some related processes, such as freeze drying, to preserve the purified products.

Viral Insecticides [13]. Viral insecticides may replace persistent chemical insecticides (e.g., DDT), during the next decade or two, for protecting forests and agricultural crops because the viral material offers specificity without side effects. This is particularly true for certain highly destructive insects, such as the tussock moth, eastern tent caterpillar, European pine sawfly, and the cotton bollworm (alias corn ear worm or tomato worm). Each of these insects does $50-100 million damage per year in the U.S. alone, in spite of the widespread use of chemical insecticides. Recent reductions in the use of chemical pesticides, such as DDT, have been accompanied by alarming increases in destructive insect populations. In the currently available form, the viral insecticides cost about $45 000-50 000 per pound. About 1 ton of virus for each of the above insects would be required per year in the U.S.; about four times that amount worldwide. The annual market would, therefore, be about $500 million in the U.S. and $2 billion worldwide. It is assumed that the FDA and counterpart organizations in other countries would not sanction widespread use of the present relatively crude or impure material, which is contaminated with bacteria. Current preparation methods depend upon various purification processes, including centrifugation, but large-scale preparative electrophoresis may be the only way of isolating some of these viruses in an ultrapure state and with a high degree of viability [9]. Preparative electrophoresis on earth is, of course, severely hampered by convection and sedimentation. Electrophoretic purification of the world's supply of five viral insecticides would require the use of about 150 tons of supplies (principally electrolyte) per year.

Vaccines. While we cannot predict exactly which vaccines will be in widespread use 10 to 20 years from now, we generally can predict what the total usage of vaccines in the U.S. and worldwide may be. Present U.S. consumption of the 10 most common vaccines amounts to about 60 million doses per year [10].

If we accept the World Health Organization's prediction of a world population, in 1990, of 5 billion people, and a public health level equivalent to the present-day U.S., world consumption of these vaccines should be 1.5 billion doses per year.

Normally, 1 g of active ingredient contains enough vaccine for 100 000 people, although it is administered in more dilute form. Therefore, processing any one (typical) vaccine in space will require transporting about 10 000 grams of active ingredients per year (22 lb per year) [10]. Using the same assumptions about electrophoretic purification as are used elsewhere, this corresponds to 4400 lb of water per year per vaccine purified. Vaccine production rules and regulations, however, would probably require a dedicated module for each vaccine [11]. Therefore, in effect we will have 10 loads per year if we assume the preparation of a year's supply of each of 10 vaccines. This may permit the use of excess weight capacity for carrying some inert payload, or perhaps an arrangement could be made to carry several compatible vaccine production units at the same time, but only one could operate at a time.

Cells and Other Biologicals. Many biologicals are separated and analyzed by electrophoresis. However, very few preparative operations are performed. It is quite clear, however, that it would be desirable to conduct preparative electrophoresis, especially of the cells and of products larger than can even be analyzed now in gels or on paper [14]. The current research on cells in connection with cancer research [15], for example, would suggest the future need for a considerable quantity of blood separation work. This has been roughly estimated at 10 Shuttle loads per year at about the end of the century.

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# EXTRATERRESTRIAL IMPERATIVE

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## Introduction

"Earth is the only luxury passenger liner in a convoy of freighters loaded with resources. These resources are for us to use after earth has hatched us to the point where we have the intelligence and the means to gain partial independence from our planet — and where the time has come to convert our earth from an all-supplying womb into a home for the long future of the human race, finally born into the greater environment of many worlds." Krafft A. Ehricke, a Space Age pioneer, is Chief Scientific Advisor, Advanced Programs, Space Division, North American Rockwell. This article is based on a talk to the National Space Meeting of the Institute of Navigation, Huntsville, Alabama, in February 1971. It contains excerpts and condensations from a forthcoming book of the same title by the author and E.A. Miller, to be published by Doubleday, Inc.

Once earth was, to man, the center of the universe — for all practical purposes, infinite and indestructible. Man's mind and soul evolved in this infinite world. He has known no other. Then, astronomy reduced earth to a tiny planet, circling an average star somewhere in an unlimited universe. But, totally conditioned to boundless environment, man's social, political and economic behavior continued as if earth were infinite and indestructible.

In the past 100 years, industrialization, world commerce, world wars, the "bomb," technology, population increase and, finally, pollution have progressively turned our planetary "infinity" into an illusion. Avoidance of war, still so recently the cherished panacea for all of man's problems, now proves to be too simplistic a goal. The pollution issue has added another dimension to man's capability of provoking catastrophes on a global scale.

Concurrent advances in planetary exploration drove into public awareness the not-so-new recognition that earth is a singular world in this solar system. After 500 years of bold and vigorous expansion, a reaction has set in. Man seems to be locked into a cosmic reservation that, for all its wealth, threatens to be a scanty Eden for his numbers and aspirations in the future.

The result is a new kind of disillusion, a wave of pessimism that tends to undermine man's confidence in a soaring future — and therewith, in his nature which, some claim, must be altered radically to conform with what is called insurmountable limitations. Confidence in a soaring future — spiritually as well as materially — is the essence of our techno-scientific civilization and Western man's greatest message to mankind. Erosion of this confidence threatens the value system and weakens the drive on which our monumental accomplishments rest, ever since the dawn of the Renaissance. And, nowhere are the roots of the Renaissance spirit more deeply embedded than in history's boldest social achievement, the United States of America.

A science policy that places the protection of our environment over man's overall needs of tomorrow is not realistic, however well-meaning, because preservation of the environment is only a necessary, not a sufficient requirement. It is no more sufficient for the preservation of man than is a pretty cage for the preservation of an animal born free in the wilds of an infinite world.

Space is obviously not a panacea for all of man's problems. Neither is earth, in the long run, because of its sensitive biosphere and its limited resources. We need both. Man has needs that will outgrow his planet in time. This is not an unrealistic notion — to presume that he will not try virtually anything to satisfy these needs, is. These very needs are so powerful that they — not his inability to see what he is doing — have put man and environment on their present collision course.

The notion that man will, in the centuries and millennia ahead, submit to a slowly declining living standard in harmony with a slowly degrading terrestrial environment is, of course, not an impossible one — but it is rather absurd. A healthy mankind is not that docile, stretching, and growing on challenges and impossible dreams; and it makes little difference whether these challenges and dreams are found on earth or beyond. Man's relation to nature has always been dictated by two passions — love and conquest.

Preservation, therefore, has a much deeper meaning in our time than ever before: that is, not only must we preserve our world's environment, we must also preserve the reality of our world's infinite expanse because man's nature is attuned to it as much as his eyes are attuned to the sunlight spectrum. This means that if we were to single out our one overriding generic responsibility to future generations, it is that we should lay the foundations for a world in which man can act as he must or, in any case, as he does. For modern man, with his powers, this is a world which is what earth alone once was to earlier man. It is not merely a world that is a gilded environmental cage where he can only act as he should by the imperatives of a static existence, or else perish. This means we must give man of tomorrow a world that is bigger than a single planet.

Of course, man should strive constantly to apply a higher degree of reasonableness to his affairs in order to improve the quality of life, even within the limits of terrestrial resources. But it is a fact that man finds his powers of intelligence and reason perpetually distorted by instinctive drives and emotional forces. If we expect this to change significantly in the foreseeable future, we are not being realistic — and neither will be our policy and planning.

We have no effective alternative but to plan for a world in which earth and space are indivisible. We still have time to accomplish the transition.

A realistic assessment of the present situation does not support the apocalyptic claim that this planet will be destroyed in the short order of a a few decades. The very awareness of the dangers ahead triggers remedial action. It is still within our control to reduce the worst transgressions, and subsequently proceed to deal with the more subtle dangers as we become progressively more knowledgeable and capable. Remedial and ameliorative measures can be introduced judiciously; the pace of change depends upon the crisis level of the problem.

In this manner, we can assure for ourselves a viable grace period — of the order of a century — during which to accommodate (1) a growing world population, if the growth rate slows down; (2) a growing world consumption rate, if earth resources management is improved by action in space and on the ground; and (3) growing industrial-agricultural productivity, if that productivity is ameliorated by the benign industrial revolution.

The indivisiblity of earth and space will enhance and favor the inviolability of earth more safely in the long run than can planetary confinement of man. Since the beginning of recorded history, it has been a fundamental goal of civilizations to search for civilizing motivations of their cultural activities. Where will this continued search have a greater chance of success — in the shrinking world of earth or in the expanding world of indivisible earth and space?

Recognition of the uniquenes of our planet has become part of conventional wisdom. But, like everything, uniqueness is not all good. Moreover, our planet is not all that unique. Earth shares many common characteristics with other planets, especially the rocky planets and asteroids (Fig. 1). Within the next 100 years, the nonuniqueness of earth will play a growing role in our attempts to preserve this uniqueness without paralyzing our future. This is not man's only environment, merely his only unique environment.

Earth's unique features are its atmosphere, huge hydrosphere, abundant biosphere and, therefrom, vast deposits of fossil energy. These features provide us with the only livable planet around. Their deterioration by pollution precipitates an environmental crisis.

But this uniquenes cuts both ways: it is the basis of our existence. But it is also the principal constraint on man's industries and technology, on which he must rely to sustain his growing numbers. This is because the uncultivated, unprocessed biosphere has long ceased to satisfy man's needs. Nature could sustain only a fraction of today's 3.7 billion people on a very modest living standard, probably not more than a billion. (Only 300 years ago, at the end of the preindustrial era, the world population was about 500 million; thus, 1 billion is probably a generous estimate.) Therefore, 3.7 billion people must produce to barely survive. They must produce much more in order to provide a bearable standard of living. They must produce at a feverish pace to sustain 6, 10 or 15 billion people.

In the last analysis, the question before us is whether we will continue in the long run to insist on endangering the unique environment of earth — our greatest basic resource, if left as much untouched as possible to exploit resources that are not uniquely earth's and to carry out industrial activities that are not tied to earth's unique environment?

The nonuniqueness of earth is as important to our future as is its uniqueness. The fact that we do not have to depend on earth for everything is the key to our future. It makes possible the gradual evolution of a practical division of labor in an indivisible earth-space continuum — a domain of many environments, each serving us to maximum advantage and each assuring the preservation not of the one but of the two great uniquenesses of this solar system, man and earth's biosphere.

To achieve this division of labor, man needs only to engage the most valuable of all the unique resources at his disposal: his intelligence and his determination. Will we use this resource properly and in time?

One might anticipate for the next 100 years an increase in world consumption level by, at least, a factor of 40, whereas, a more likely increase is a factor of 160 and quite possibly more.

The estimated electric power consumption, for 1970, is about 1.7 trillion kW-h for the U.S. and about 6 trillion kW-h on the world level. These figures are twice the 1960 value. At such an annual growth rate (about 7 percent), the world's energy consumption will pass the 100 trillion kilowatt-hour mark by 2010. The thermal heat release is, characteristically, 2.5 kW-h per electric kilowatt-hour. The heat is released into the environment, passed through the biosphere (hydrosphere, atmosphere) and, eventually, is radiated into the infinite heat sink of space. If sufficiently large this heat release becomes a thermal burden on the biosphere.

The projected global thermal burden in the form of waste heat from electric power generation amounts to about 30 trillion thermal kilowatt-hours in 1980 (Fig. 2). This is only about 8 percent of the solar energy absorbed annually by all terrestrial vegetation (3800 trillion kilowatt-hours). At the present 7 percent growth rate, this value would be reached by 2050, thus, doubling the natural heat flux into the biosphere. By the year 2110, the thermal burden would equal the solar energy absorbed annually by the earth's hydrosphere (about 221 600 trillion kilowatt-hours). But these figures are not realistic, since long before most of the basis of our biosphere — the photosynthetic process in the oceans — would have been destroyed and oxygen regeneration of our atmosphere seriously impeded if not halted altogether. At the previously mentioned growth factors of 40 to 160 between 1970 and 2070, the thermal burden from electric power generation would, by 2070, reach 16 to 63 percent of the solar energy absorbed annually by terrestrial vegetation. This range is already quite critical, considering that the actual value is likely to be closer to the upper than the lower value, and considering further that actual heat release will cause local concentrations of extremely biocidal thermal pollution. At 16 percent, the heat influx into the biosphere is about 600 trillion kilowatt-hours, enough to raise the temperature from ambient to the boiling point of some 60 percent of all fresh water lakes on earth. Thus, it is a definite possibility that fresh water life is mortally threatened on a continental scale in the highly industrialized regions of earth. Ocean life in the estuaries and other fertile regions can be seriously threatened by the combination of temperature increases and chemical pollution. Pollution watch of continental coastlines, from satellites or space stations, will become increasingly important.

## Space Power Plant

Yet, without energy our techno-scientific civilization cannot be preserved. If our techno-scientific civilization collapses, the lives of billions of people cannot be preserved — a death toll equaling or exceeding that of a massive nuclear exchange. Thus, energy is one of the sectors of man-environment interaction in which we will reach the confrontation phase within 100 years from now. New approaches are required.

Three benign methods of electric power generation are available, constituting long-range solutions to man's energy problems: geothermal, nuclear fusion, and space power generation. It is quite possible that a combination of these will provide the most desirable flexibility to meet future practical needs.

The third approach to a long-range energy solution is the generation of power in space. With the advent of beamed power transmission technology it becomes possible to generate power in space for consumption on earth.

Beamed power transmission will be of almost unlimited consequences for space operations and the opening of moon and planets. Power generation in space for power consumption on earth is a significant example of the future division of labor in the indivisible earth-space continuum of human activity (Fig. 3).

Power generation is the conversion process of energy from its primary form (heat or radiation) to energy in its desired form. On earth, the desired energy form is electricity. In space, the desired energy form is radiation, suitable for transmission to the surface. In any case, it is the initial conversion of primary energy that produces the greatest thermal waste and the greatest chemical waste if the power plant operates on coal or oil. Therefore, transplanting this process into space removes the bulk of the environmental burden associated with the generation of electric power.

Power generation in space involves a primary energy source, conversion to electric energy and conversion to beamed energy, beam transmission to a central receiver ground station, reconversion into electric energy and regional distribution to consumers through high-voltage grids. At least 80 percent of the thermal waste produced in the entire process is generated in space and radiated directly into the cosmic energy sink without first passing through the biosphere. The conversion process from beamed to electric energy in ground stations is better than 80 percent. The chemical or nuclear (fission) waste burden is eliminated entirely.

The primary energy source of a space power plant could be solar radiation or nuclear energy. Solar energy at the earth's distance from sun is rather diluted. One square meter (about 10 square feet) receives about 12 200 kW-h annually. To generate 1 trillion kilowatt-hours annually for the terrestrial consumer at 10 percent overall efficiency requires a solar radiation interception area of about 8 billion square feet (200 000 acres or 320 square miles; or a square measuring 56.6 by 56.6 miles). The actually obtainable overall efficiency will lie between 10 and 15 percent, so that the required intercept area for 1 trillion kilowatt-hours will measure between 320 and 214 square miles. (A recent study by Peter Glaser of a 10-million-kilowatt solar electric power generation system arrived at a solar cell area of 25 square miles. This would correspond to an overall conversion efficiency of 11.2 percent.) This or preferably, a modularized version consisting of, say, several smaller primary energy conversion systems is certainly feasible, considering the technology of the next 30 to 50 years.

An alternate way of using solar energy is by means of radiation collectors, an array of mirrors in whose focal region solar radiation is absorbed by heaters and converted to electric power. Depending on the conversion system, the efficiency of this system could exceed that of a solar array, resulting in a smaller collector panel whose size, however, nevertheless measures in square miles.

The concentrated form in which nuclear energy is available offers many advantages in terms of the cost of establishing the station and its maintenance. Breeder reactors could be used, combining the production of valuable isotopes and uranium-235 with the generation of electric power. The radioactive substances would be stored in space and brought to earth safely, in space shuttles, on the basis of need. The most concentrated form of large-scale nuclear-electric power generation — short of fusion generators — would be a combination of gas core reactor (GCR) and magnetohydrodynamic (MHD) converter. The degree of compactness of such a system can be inferred from the fact that a 15 000 kW (earth) solar power generator system (producing 0.13 billion kilowatt-hours) would require an interceptor area of 1000 by 1000 ft, whereas a GCR-MHD system of the same capability would measure less than 20 ft in diameter. The weight of a GCR-MHD system would run between 70 and 80 percent, possibly less, of the solar energy system.

Nuclear energy is far less difficult to handle in the vacuum of space than on earth and, of course, all apprehensions (which are known to extend far beyond the normal environmental misgivings) relative to the large-scale use of nuclear energy in terrestrial power plants are eliminated. Transportation of fissionable material by a Space Shuttle involves negligible hazards, because the Shuttle is designed for safe abort. The use of nuclear reactors in orbit is for all practical purposes perfectly safe, since the need for neutron reflectors and shielding renders the structure virtually impregnable for space debris or for meteoroids of any practical size.

Thus, we have, for space power plants, a choice of two primary power sources — solar and nuclear — and an eventual optimal arrangement might involve an integration of both into an overall system.

The size of the beam transmitter area depends on the practically feasible power density. This density can vary from many kilowatts per square centimeter for laser beams to the order of 0.5 W per square centimeter for microwave beams. For the latter case, transmission of 1 trillion kilowatt-hours annually at constant power level requires a transmitter area of 10 square miles. On earth, the dimensions of the receiver complex are determined by the allowable power density of the beam. At a safe representative power density of 0.005 W per square centimeter, a receiver area of 1000 square miles is needed to process 1 trillion kilowatt-hours annually on a constant power level basis.

Tens to a few hundreds of billions of kilowatt-hours annually are more representative for regional power consumption. In that case, receiver antenna areas of the order of hundreds of square miles are needed. These are not impractical requirements, even in densely populated areas such as Europe or Japan.

## Maximum Dwell Time

The most obvious, but not the only appropriate, location for terrestrial space power plants is the equatorial geosynchronous orbit (22 300-mi altitude). Because in such orbit an object is in a stationary position relative to the area over which it is located, one power plant is needed to serve a given region (e.g., North America or Africa). But there are also suitable elliptic orbits, for instance, polar elliptic orbits with their most distant point (apogee) over the North Pole (Fig. 4). This assures maximum dwell time of the power plants over the northern hemisphere, where the majority of the power consumers are located (and probably will be even 50 years hence), and where the know-how is amply available to operate and maintain the huge receiver installations. Position over the northern hemisphere allows simultaneous coverage of all longitudes down to a certain latitude depending upon altitude; whereas, in geosynchronous orbit all important latitudes are covered, but only over a limited range of longitudes. Because of the circumglobal coverage of the northern hemisphere in polar elliptic orbits, the period of revolution in the orbit matters little. The polar route, therefore, also offers greater flexibility in the international availability of spare power plants should the operation be a joint project by nations of the northern hemisphere. North America, Europe, the Soviet Union, Japan, and other nations are covered, simultaneously, as the power plant passes through the farflung arc above the North Pole, able to direct its beam where needed. Coverage of the northern hemisphere down to 40 deg latitude encompasses most of the U.S. (the southern strip and Mexico could be supplied by a high-voltage grid), practically all of Europe, the Soviet Union, northern China and northern Japan. If an orbit with a period of 12 hours is chosen, for example, four stations could provide continuous, overlapping coverage of the northern hemisphere down to 40 deg latitude. The stations can be established and maintained more cost-effectively than in geosynchronous orbit. To reach the same countries from a geosynchronous orbit, with some overlapping, the same number of stations is required. It is not important at this point to make a case for the superiority of the one or the other orbit. Of importance is the fact that several alternatives are available.

## Manufacturing in Space

Space manufacturing has two basic aspects: (1) utilization of unique extraterrestrial environmental properties (such as different gravity levels and vacuum); (2) reduction of terrestrial environmental burdens from the surface, by applying the principle of division of labor between earth and the extraterrestrial domain. Just as earth is not a unique place for generating power (other than by fossil fuels), so is it not a unique place for manufacturing (other than for products relying on the processing of large amounts of rock or fossil or other organic materials).

Space environmental utilization is of interest in metallurgical processes, glass processes, crystal growth processes, and biological manufacturing processes. In the metallurgical field, unique alloys and metal products with superior properties (weight, strength, purity, etc.) can be produced. Glasses with superior optical characteristics and base materials for advanced semiconductors can be produced in the low-gravity environment of space. Single crystals of larger size, higher purity and higher crystallographic perfection for electronic, optical, and other applications can be manufactured in space more than on earth. Finally, biological materials (serums, viruses) of highest purity can be produced in weightlessness. Initially, the biological and crystal growth manufacturing groups offer the greatest promise, because they combine significant product improvement over terrestrial manufacturing with acceptable transportation demands.

The second aspect — the reduction of terrestrial environmental burdens from the surface of the earth — can have a far more incisive effect on our world and on the future of man's resource base. It involves both the environmental effects of the manufacturing process proper, and the environmental effect of extracting the mineral resources.

In principle, all industrial activity could be transplanted into space, that is, into near-earth orbit. The worthwhileness of it depends on the objective. The objective must meet a vital need to justify the effort.

If reduction of the terrestrial thermal burden is the objective, then the move would defeat its purpose if the raw materials must be supplied from earth. The reason is simply that delivering a ton of material into orbit releases more energy into the biosphere than is released in processing either the raw material (primary processing) or in working it into manufactured goods (secondary processing). Using Saturn V as an example, virtually the entire energy content of the first stage, namely 5.6 million kilowatt-hours, is injected into the biospheric portion of the atmosphere — 41 000 kW-h per ton of payload delivered into low orbit. Presently, it takes 17 000 kW-h to gain the 1 ton of aluminum from 2 tons of alumina. In the future, this value is likely to decrease to about 15 000 kW-h. In generating 15 000 kW-h of electricity, 30 000 to 37 000 thermal kilowatt-hours are released into the environment. In transporting 2 tons of alumina (plus consumable carbon for the electrodes used in the electrolytic process of extracting the aluminum), approximately 90 000 kW-h would be released into the biosphere by a Saturn V type transport to produce 1 ton of aluminum.

Of course, Saturn V would not be a suitable transport. Conditions could be improved by the use of more advanced nonchemical transports. The ultimate would be a gas-core, reactor-powered, air-breathing transport, capable of reaching orbital velocity by air-heating at only negligible fuel consumption for final maneuvering in space. Such a vehicle would release about 3500 thermal kilowatt-hours per ton payload into the atmospheric biosphere, or about 8000 kW-h per ton of aluminum produced in orbit. But even this would provide a significantly favorable thermal balance only for aluminum, since the next highest consumer (electric furnace ferroalloys) requires less than 6000 kW-h per ton.

Besides the thermal burden, chemical pollution is, in principle, a possible reason why it might be desirable to remove an industry from earth into space. But at least in the metal manufacturing industry, as distinguished from the primary metal industry (mining, metallurgy), pollution by itself is not likely to become a sufficient justification. The principal chemical burdens in the manufacturing industry are generated by industries which depend to the greatest part on organic raw materials that are uniquely earth's.

Compared to the secondary (manufacturing) metal industry, the primary sector (mining, refining) is a far worse chemical polluter. It would, then, be more worthwhile to remove the primary sector.

If delivery of metals from extraterrestrial sources is considered, orbital manufacturing assumes a different complexion. Raw materials are delivered at no terrestrial thermal burden. Little thermal burden is involved in delivering products from space to earth, even if the atmosphere is used as energy absorber. The bulk of the energy is dissipated as heat in the outer and upper atmosphere (above 100 000 ft), which is outside the biosphere. Thus, metals and metal products can be delivered from the extraterrestrial domain for indefinite time periods with virtually no detrimental environmental effects, certainly incomparably smaller effects than if they were produced on earth.

## Minerals and Our Planet

Except, perhaps, for a very distant speculative future, the only way to obtain the needed metals in needed quantities is through the processing of minerals. It is, therefore, not possible to think in concrete terms of a condition in our technological civilization where we will no longer be dependent on minerals.

Mining produces the largest amount, so far, of inorganic waste: upwards of 1 billion tons annually in the U.S. alone, exceeded only by the 1.3 billion tons of organic agricultural waste (manure and refuse). Compared with the wastes from mines, the amount of wastes and sewage from manufacturing plants, homes and office buildings (350 million tons in the U.S.) appears almost small. Acids from metal processing are among the most biocidal polluters.

But the ultimate problem is the finite amount of reserves available in the earth's crust. Only a relatively very small amount of reserves of each metal is found in ores in sufficient concentration to be mined economically with present methods. This is especially true of many important nonferrous metals.

Can terrestrial reserves support an at least 40- to 160-fold increase in the next 100 years; and, more importantly still, can they sustain this consumption level for a long period of time? Based on presently known reserves, the answer is clearly negative for a number of important nonferrous metals, such as lead, zinc, silver, mercury, bismuth and probably also copper, tin and cobalt. There is always the possibility that new ore reserves will be discovered, especially in conjunction with earth resources surveys from space. There are also certain possibilities in recycling, but they can at best only slow down unavoidable dissipation and, moreover, are of no help in satisfying demand increases. Also, there is the possibility of mining ever poorer grades down to common rock.

What about the oceans? Most mineral and chemical resources will, in the next 50 years, be those that can be gained from seawater and from the relatively shallow continental shelves. But these are the biologically most important and most sensitive regions of the oceans. Extracting metals from the ocean bottom at depths of 1000 ft or more requires the development of an abyssal technology, an accomplishment that is no easier or less costly than developing the space technology required for extraterrestrial mineral resource utilization. Even aside from development problems, the vacuum technology of space cannot help but lighten the terrestrial burden and the threat to life's roots in the oceans, while ocean-bed mining cannot help but do the opposite, since it appears unavoidable that effluents and tailings are pumped directly into the sea.

Land mining at increasing depths faces a formidable problem of locating promising ore in the first place. Exploiting reserves located at great depths requires also the development of a new, abyssal technology. Exploiting progressively lower-grade ore and, perhaps, eventually rocks will, like ocean floor mining and land mining at great depth, steadily increase production costs. In addition, mining lower grades demands the processing of growing amounts of material, causing rapidly spreading land devastation, and pollution. Mining by nuclear detonation — the only way in which the exploitation of ore below certain grade levels, or of rocks, could be made economically viable — appears to be out of the question in view of the environmental implications except, perhaps, in combination with the exploitation of reserves on land at great depths beyond the danger of radioactive gas escaping to the surface or radioactive substances poisoning ground water (Fig. 5).

But even if the full potential of science and technology is brought to bear, the mineral resource limitations of one single planet simply cannot sustain continued exploitation at much higher than present levels on a long-term (even centuries long-term) basis, because environmental constraints do not permit exploitation of even the limited reserves. Thus, "placing all our eggs" into the terrestrial basket adds up to a losing proposition.

Minerals are the one natural resource that is widespread in the inner solar system and the asteroid belt. It is also a fact that the earth is more sensitive and, in this sense, a less suitable world for massive mineral exploitation than any other body in the inner solar system — as the furniture of the living room is a less suitable source of wood for the living room's fireplace than supplies in the woodshed or garage.

Earth is not merely a spaceship. It is a member of the Sun's convoy traversing the vast ocean of our Milky Way galaxy. We are separated from our sister ships by greater distances than our land surface is from the bottom of our oceans. But far more important than distance is the nature of the intervening medium.

It is very fortuitous that we need only to traverse open space to reach our extraterrestrial resources, rather than ocean depths or miles of earth's crust to reach our remote terrestrial mineral resources. It is equally fortuitous that our companion worlds are not other earths. One intelligent species is probably as much as most solar systems can accommodate. Our companion worlds are underdeveloped. Earth is the only luxury passenger liner in a convoy of freighters loaded with resources. These resources are for us to use, after earth has hatched us to the point where we have the intelligence and the means to gain partial independence from our planet — and where the time has come to convert our earth from an all-supplying womb into a home for the long future of the human race, finally born into the greater environment of many worlds.

On those worlds we can bring nuclear power to bear to exploit minerals with an efficiency that would be prohibitive on earth. This changes the basis for exploitation inasmuch as lower grades can be exploited more efficiently than on earth. We have the nuclear muscle to break an asteroid apart, or to work the crust of another planet extensively, in order to get at needed minerals.

Some will see in this a threat to soil other worlds as well as our own. But like every creature, we cannot help soiling something by living. One of the most thoughtless statements, parroted ad nauseam ever since rational concern for our environment exploded into an emotional syndrome, calls man the only animal that soils its own nest. Every animal soils its nest with the products of its metabolism if unable to move away. Space technology gives us, for the first time, the freedom to leave our nest, at least for certain functions, in order not to soil it.

Mineral exploitation is not the cleanest business in the world. But soiling an asteroid or a desolate place on another planet cannot reasonably be equated to continued soiling of the earth. Moreover, pollution assumes an entirely different, and far less critical, meaning in the context of the extraterrestrial environment. This environment is an inorganic world, exposed to a steady stream of biocidal, ultraviolet radiation and particle flares from our sun, both of which would constitute pollutants par excellence if they could flood our terrestrial environment. There is nothing that man's exploits on other worlds could add to make things worse in the vast expanse of the solar system.

Extraterrestrial mining of mineral deposits will be made possible by using nuclear explosives (Fig. 5), or possibly by nuclear fusion torches investigated more recently by Atomic Energy Commission (AEC) researchers, to break rocks and ore bodies — an extraterrestrial version of Plowshare. Absence of a significant atmosphere in most cases, and low gravitational pull, will permit easier escape of radioactive materials, thereby reducing the fallout on the worlds in question.

Metallurgical methods will have to be revised for absence of water and for use of gases of different composition than are used on earth. However, oxygen is fairly abundant in chemical (e.g., silicon) compounds from which it can be extracted. Oxygen is an important ingredient in some beneficiation methods — the first step in nonferrous metallurgy, where waste is removed, concentrating the valuable mineral into smaller bulk for subsequent steps in refining. The large energy requirements for electric smelting, high-frequency induction melting, electrometallurgy, and perhaps modified forms of pyrometallurgy can easily be provided anywhere by nuclear-electric or nuclear-thermal power plants.

## Transportation Costs

For the transportation from the moon or the planets to be economically viable, the energy must be very inexpensive and metal transporters must travel in relatively slow paths. To be inexpensive, the energy must be extremely concentrated and the materials (expellant) expended in propelling the transporters must be small in mass and low in cost; or they must be provided at the place of mining. With the exception of the latter possibility, which is uncertain, only nuclear fusion meets these conditions. Because of the large payloads, the transporter requires high thrust values. Fusion drives, operating through pulsed energy release, can most readily attain high thrust values while keeping propellant consumption low. Their operation uses a sequence of detonations somewhat analogous to the operation of a combustion engine. In the latter, a piston is propelled by chemical detonation. In the pulsed fusion drive, an elastic device absorbs the energy shock from the detonating nuclear pulse, thereby driving the spacecraft forward.

The energy-releasing device is a nuclear fusion charge of adequate strength. The energy transmitting device is an expellant which could be either a metal or hydrogen (or water), depending on design specifics of the engine.

Figure 6 surveys the propellant cost of an interorbital transport having a dry weight of 1000 tons (2.2 million pounds), capable of delivering a useful payload of 3000 tons (6.6 million pounds) from an extraterrestrial resource base to earth. In order to determine the propellant cost, the following assumptions were made:

1. The cost of the nuclear fuel is \$ 424 000 per kiloton ( $10^{-14}$ \$/erg).

2. The cost of the expellant is negligible compared to the cost of the nuclear fuel or the cost of transporting the expellant from earth to orbit.

3. The earth-to-orbit transportation cost of nuclear fuel and expellant is \$ 20 000 per ton (about \$ 10 per pound, or 10 times less than with presently projected shuttle, assuming a much larger earth-to-orbit shuttle some 30 years hence).

4. The transport carries as payload on its outbound flight the fuel and expellant needed for the return flight where its payload is 3000 tons of extracted metal.

The result is shown for three levels of transportation energy, corresponding to: (1) 10 km/sec; (2) 20 km/sec; (3) 40 km/sec each way. Lunar missions are well under the level of curve (1). Mars missions would fall near to, or somewhat above curve (1). Asteroid missions would lie between (1) and (2), Mercury missions between (2) and (3). Each curve shows the propellant cost per kilogram payload versus the nuclear energy expended on the round trip at the defined level of transportation energy.

The minima shown in Figure 6 are representative. They indicate cost figures that are economically viable, especially for the 10 km/sec and the 20 km/sec level, if compared to the cost of some metals already today.

Of course, the figures in Figure 6 are far from being the total cost — even the total transportation cost. The latter includes the cost of ship maintenance, loading and unloading, and crew maintenance during layover times in earth orbit and at the target. These additional transportation costs can presently be detailed only on a highly speculative basis. But they will hardly as much as double the indicated minima. Possible reductions in nuclear fuel cost or reductions in earth-to-orbit transportation cost would have a far greater effect.

The point to be made here is that contrary to a generally held presupposition, interorbital transportation costs can be decreased to a competitive level. Transportation costs need not be the principal constraint, 50 yr hence.

It is interesting to note that in order to bring home 3000 tons of metal from the lunar surface, a nuclear energy of only about 50 kt need be expended for the round trip; and only some 150 to 200 kt to return 3000 tons from the Mars complex or from asteroids.

Many consider this way out or look at it with derision or skepticism as to its practicality, while at the same time we are compelled by our primordial instincts to pile up vast megatonnages to keep each other in line.

## Future of Man

The central concept is the preservation of man and his future. This means the preservation of both the natural terrestrial environment and the infinite world of man, because he needs both. They were one in the past. But this one-world era is drawing to a close. In the future, they will encompass many worlds and, thereby, the world of man may become one — a world so savagely divided in the past.

But for this to happen, man's root planet must be his seat of power, not his cage — his root complex with the crown reaching to the stars. In this and in the next century, man will experience a transformation without equal since he emerged on this planet. He must have new options to cope with his altogether new existential universe.

Earth and space are indivisible. Together they represent the greater environment of tomorrow through which the balance between man and planet can be restored, so that both his terrestrial birth environment as well as the needed boundlessness of his world can be maintained for the long future.

In the greater earth-space environment a practical division of labor can be developed in which maximum advantage is taken of each of the three principal environmental regimes: earth, space, and other worlds in the inner solar system. Earth resource management from space, power generation in space for consumption on earth, and minerals from other worlds in the inner solar system — these are only the beginnings recognizable to us today of an evolution in which the nonuniqueness of earth becomes one of the important keys to the long-range future of the human race.

While we must correct the mistakes of the past, it must not be done by discriminating against the future — and that is precisely what we are doing if we do not work concurrently toward broadening our option base, especially in the greater earth-space environment. Because we are emancipated from the natural environment on a massive scale, we must invest more heavily than ever in the future of a human race that must rely primarily on its genius, not on its terrestrial environment, to provide for its future needs, physical and emotional. For we alone are responsible from now on for ourselves, our planet and our solar system to the end of our time.

Orbits are the new lands of our time. Before we even get to settle on another celestial body, we can build growing installations in space whose architecture rests as safely on the dynamic foundations of celestial mechanics as our terrestrial architecture rests on the static foundations of the ground. Earth and space must be interconnected by safe and cost-effective routine transportation.

Large space cities will eventually no longer only occupy earth satellite orbits, but circle our sun at different points in earth's orbit. Space cities, with giant factories and food-producing facilities, will maintain their own merchant fleet of spacecraft, their own raw material mining centers on other celestial bodies, and be politically independent city-states, trading with earth, forming new cultural cells of mankind whose choice of living in space has increased tremendously and adding to the plurality of human civilization.

Perhaps, as we place the extraterrestrial domain into the service of all people, we may be permitted to hope for the greatest benefit of all: that the ugly, the bigoted, the hateful, the cheapness of opportunism, and all else that is small, narrow, contemptible and repulsive becomes more apparent and far less tolerable from the vantage point of the stars than it ever was from the perspective of the mudhole.

After all, should we not take a cue from the fact that since the beginning man has placed his dreams and aspirations among the stars and his nightmares into caves whence he came?

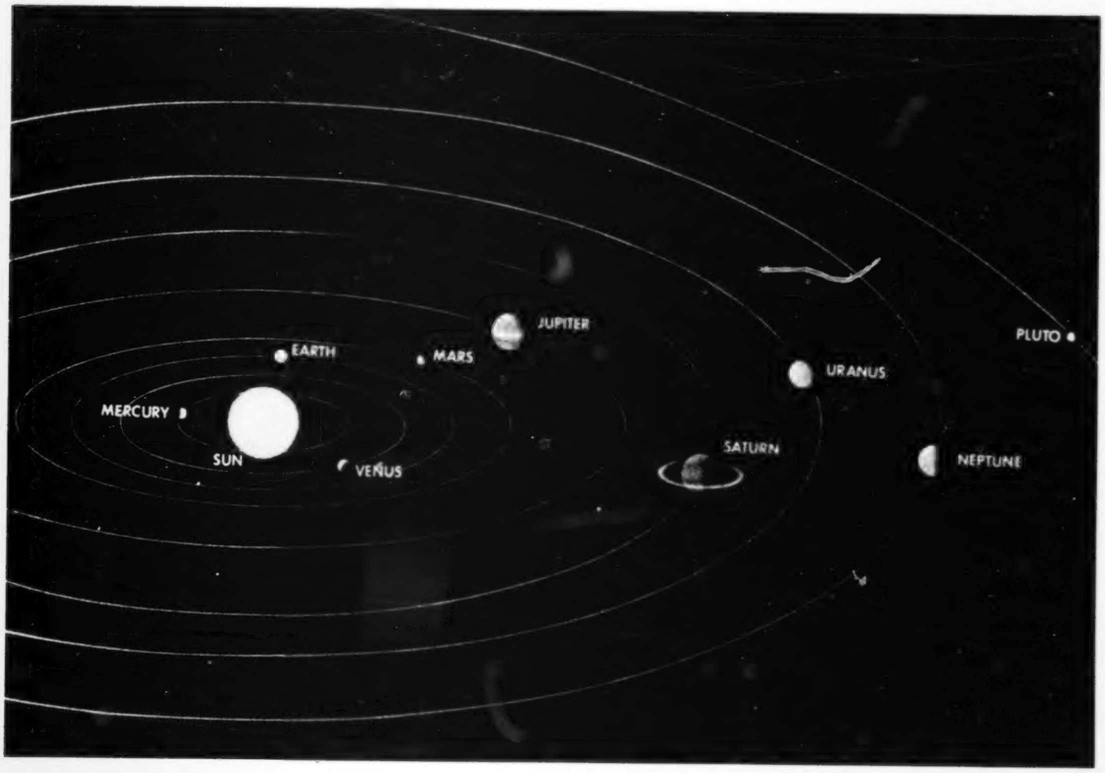


Figure 1. The solar system.

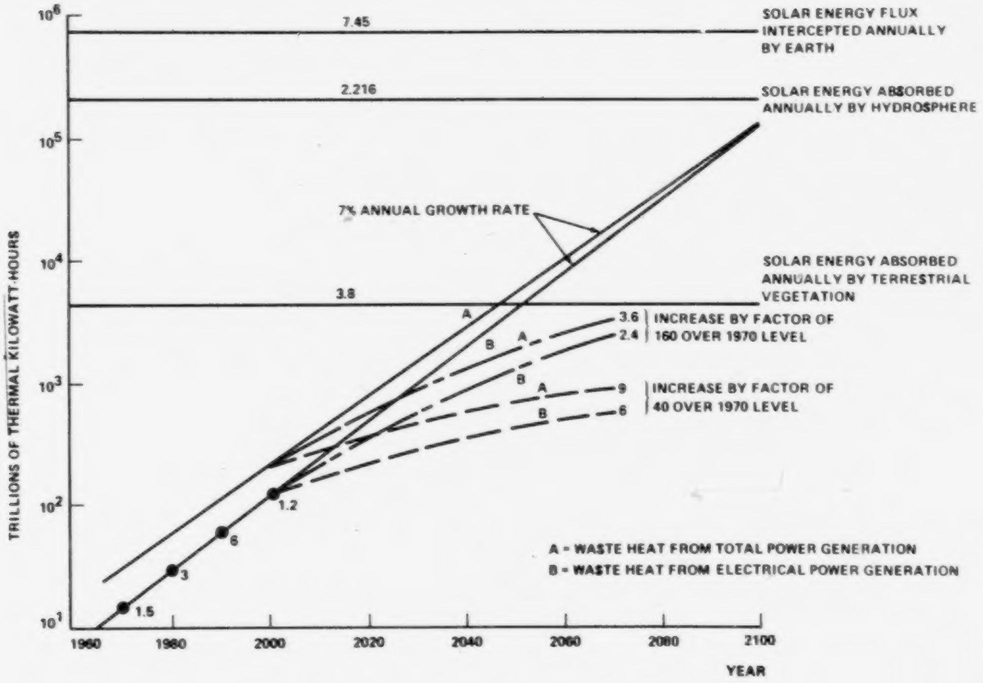
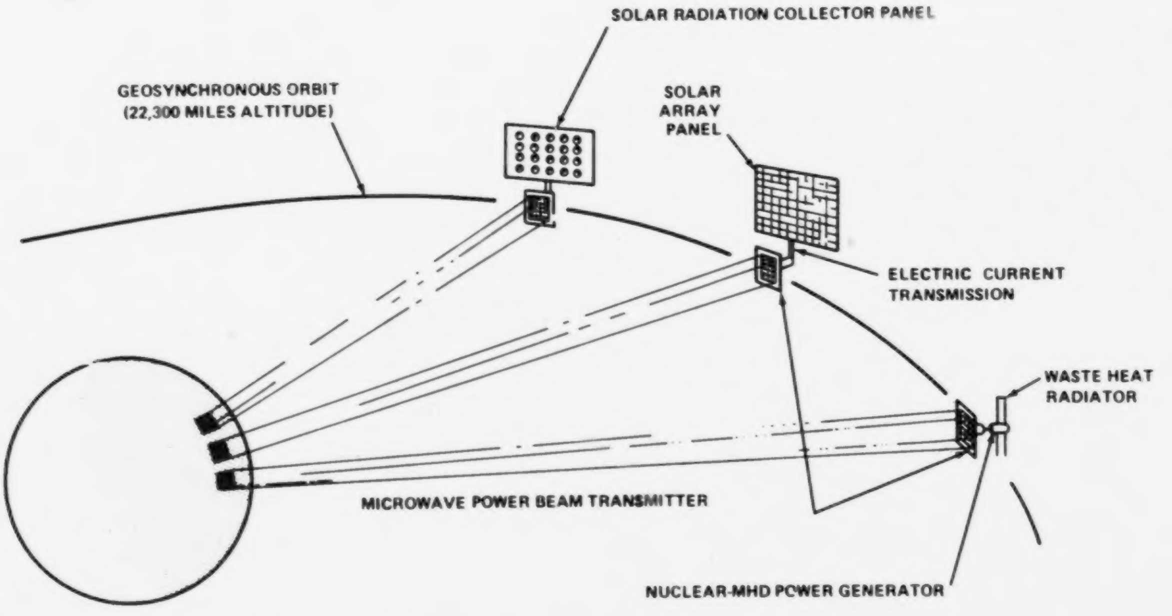


Figure 2. The thermal burden.



SOLAR RADIATION COLLECTOR PANEL
GEOSYNCHRONOUS ORBIT (22,300 MILES ALTITUDE)
SOLAR ARRAY PANEL
ELECTRIC CURRENT TRANSMISSION
WASTE HEAT RADIATOR
MICROWAVE POWER BEAM TRANSMITTER
NUCLEAR-MHD POWER GENERATOR

Figure 3. Methods of power generation in space for consumption on earth.

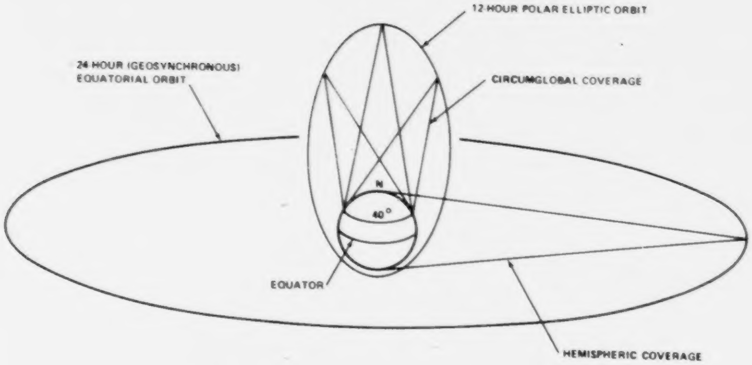
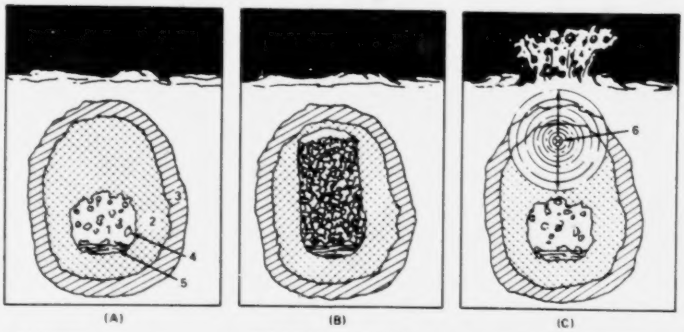

12-HOUR POLAR ELLIPTIC ORBIT
24-HOUR (GEOSYNCHRONOUS) EQUATORIAL ORBIT
CIRCUMGLOBAL COVERAGE
N
40°
EQUATOR
HEMISPHERIC COVERAGE

Figure 4. Choice of power station orbits.



1 CAVITY
2 FRACTURIZED ZONE
3 DEFORMED ZONE
4 FALLING ROCK
5 PUDDLE OF MOLTEN ROCK

FORMATION OF A CHIMNEY OF FRACTURIZED ROCK THROUGH A COMBINATION OF COOLING OF GRAVITY

FORMATION OF A CHIMNEY AND ACCESS TO FRACTURIZED MINERALS BY A SECONDARY EXPLOSION (6) TO COMPENSATE FOR INSUFFICIENT GRAVITATIONAL FORCE

Figure 5. Extraterrestrial mining.

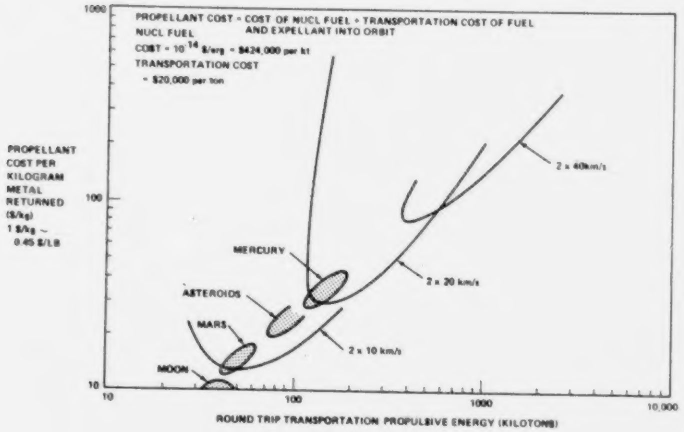


Figure 6. Interorbital transportation propellant cost for 3000-ton payload nuclear pulse freighter for specific destination.

# SESSION VIII

# BENEFITS TO FUTURE POWER GENERATION AND ENERGY PRODUCTION

# POWER AND ENERGY FOR POSTERITY

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## Abstract

During the past 20 years, the increasing electrical and thermal energy demands of aerospace vehicles have led to the development of highly sophisticated energy generation and storage systems. High-efficiency solar arrays, very reliable batteries and fuel cells, highly efficient turbogenerators, zero-loss superconducting energy storage devices, promising magnetohydrodynamic (MHD) power systems, high-energy density solar collectors, and reliable thermionic and thermoelectric electrical converters have all been developed to satisfy our aerospace needs. Since one of 20th century man's greatest needs is for usable energy, application of this technology to benefit the general public was considered. The utilization of these systems for pollution-free generation of energy to satisfy mankind's future electrical, thermal, and propulsion needs was of primary concern. Ground, air, and space transportation; commercial, peaking, and emergency electrical power; and metropolitan and unit thermal energy requirements were considered. Each type of energy system was first analyzed in terms of its utility in satisfying the requirement, and then its potential in reducing the air, noise, thermal, water, and nuclear pollution from future electrical and thermal systems was determined.

## Introduction

During the past two decades, the increasing electrical and thermal energy demands of aerospace vehicles have required the development of highly sophisticated and unique energy generation and storage systems. For the megawatt aircraft electrical power requirements, MHD generators, and high-performance turboalternators have been investigated and are being constructed. The need to achieve lightweight MHD generators led to the study of superconducting magnets, which opened the way for the development of lightweight, low-temperature, and superconducting electrical energy storage systems. On the other end of the power and energy scale, electrical and thermal energy conversion and storage systems had to be developed in an extremely lightweight form to satisfy manned spacecraft and satellite energy needs. Since fuel and oxidizer systems for the long lifetime space missions would be very heavy, energy conversion systems for these applications concentrated on using free solar energy or lightweight nuclear energy. Solar cells, solar collectors, thermoelectrics, and thermionic conversion devices were developed to use these energy sources.

Although the development of higher performance energy systems for aerospace application is a continuing process, it seems appropriate, at this time of ecological awareness, to reflect upon the benefits that man might derive from the recent developments in this area. In particular, the great care taken during the evolution of these systems to either utilize natural energy sources or operate at very high efficiencies suggests that their applicability might be toward reducing pollution from our major energy generation and conversion processes. With this in mind, we have reviewed the technology and recent developments in aerospace energy systems in order to assess their potential promise for reducing the various forms of pollution associated with energy generation processes. All of the new energy systems seem to have some merit in this area. Although several interesting applications were found and are conceptually discussed, a detailed analysis to determine their payoff was not carried out. In addition, the cursory investigation carried out in this paper is by no means exhaustive. It is the authors' hope that this discussion of aerospace energy systems will lead to new ideas on their applicability in solving some of the world's energy problems.

## Solar Arrays

Solar arrays have been developed by the Air Force and NASA to provide electric power for space satellites. The advantage of solar arrays is that they utilize solar energy for power generation, and hence, no heavy fuels and oxidizers need be launched for their operation. The disadvantage of arrays is that they operate only in sunlight. In order to satisfy the spacecraft's need for continuous electrical power, energy storage systems, such as batteries or fuel cells, must be employed for dark-time power.

Solar arrays have been developed to the point where they can be launched in a rolled-up configuration and deployed into flat plates in space. They are efficient, lightweight, and last for as long as 7 years in space without maintenance. Their main performance disadvantage is their cost, which could be substantially reduced with greater usage and increased production.

They are ideally suited as a pollution-free method of generating electrical power. They generate no air or water pollutants, and are noiseless and nonnuclear, using nothing but sunlight for power production. Commercial solar power plants could be designed in two ways. Long lifetime systems could be placed in an orbit around the earth where electrical power would be produced by the array and converted into microwave energy, which could be beamed down to earth and reconverted into electrical power. While such a system would have a very high initial cost (because of launch), its operating cost would be negligible. A typical system might be a 5-square mile array at synchronous orbit which could supply 10 million kilowatts of power for 23 hours a day. An earth-based battery storage bank would be needed to cover the remaining hour. The alternative system would be a ground-based array/battery complex. In this case, the initial cost is low but the operating cost is high (replacement, damage). In addition, the storage system would be much larger (8-12 hours versus 1 hour), and weather would greatly affect the system's operation.

Although solar array power production is essentially pollution free, application of this approach is being delayed because of the economics.

## Solar Collectors

Solar collectors can be used to convert solar energy into highly concentrated thermal energy. Until last year, spacecraft engineers were primarily interested in using solar collectors as a heat source for electrical power generation turbogenerators or thermoelectric devices were used to convert the thermal energy to electrical power. Recently, requirements for large amounts of heat on spacecraft have led to renewed interest in solar collectors and programs to develop these solar to thermal conversion systems are currently underway.

Solar collectors have been built in a wide variety of sizes. For space systems, collectors capable of delivering several hundred kilowatts of thermal energy have been constructed. The collectors operate at very high efficiencies (~ 90 percent), are extremely lightweight (0.2 lb/ft$^2$), and have long lifetimes (5-10 years) in space.

They could be used to provide both thermal and electrical power for either small units, such as homes, or large industrial complexes. Like solar cells, collectors are noiseless, nonnuclear and use nothing but sunlight for energy production. Although it would be possible to place solar collectors in orbit and transfer the collected energy to the earth, a more practical approach would be to utilize ground-based collectors. Heat storage systems, using the energy stored during the phase change of an alkali metal (like sodium) from the liquid state to the vapor state, could be employed to maintain constant heat output during dark periods. These heat storage systems have been built using heat pipe technology and have lifetimes of several years.

Housing and industrial complexes built around central solar-collector systems, providing both thermal and thermally converted electrical power, should be considered. The electrical conversion systems could be either centrally located or placed appropriately within the using subunits. Approximately 100 ft$^2$ of collector would be required for thermal input to a single family unit. In order to reduce costs, very large solar collectors could be used for inputs to several units.

The major disadvantage of ground-based solar-collector thermal heating and conversion is its performance dependence on weather. Heavy cloud cover virtually destroys the collector's ability to deliver thermal energy. There are several approaches which could compensate for this disadvantage. Collectors could be used primarily in areas where bad weather is rare. Oversized units with large storage systems could be employed in marginal areas. Auxiliary nonsolar power systems could be used with solar collectors to cover these blackout periods. Finally, solar collectors could only be utilized to provide auxiliary power for specific applications, such as air-conditioning, when heavy cloud cover is not a problem.

## Batteries/Fuel Cells

The conversion of chemical energy directly into electrical energy can be accomplished in either a battery or a fuel cell. The only difference between the two lies in the state and physical relationship of the chemical reactants going into the reaction. Both fuel cells and batteries can be made to operate in a primary mode where they are never recharged, such as flashlight batteries, or in the secondary mode, where recharging is used to extend their useful lifetime. Batteries and fuel cells which can operate for many years with thousands of charge/discharge cycles have been developed for aircraft satellites. Since most batteries and fuel cells are modular, there is really no limit to the power levels one can achieve using them. In order to reduce launch costs and increase aircraft payload fractions, a very large development effort has been underway to reduce the weight of batteries and fuel cells. Primary batteries, with excellent reliability, have been developed with power densities of 100 W-h per pound for 100-hour applications. Secondary batteries and fuel cells, with 5-year continuous use lifetimes, have achieved power densities of 10 W-h/lb.

Although the use of batteries for special applications in industrial and household applications has been considered, and in some cases, utilized, the general use of these storage systems is now being studied. Battery-driven electric automobiles, where lifetime, weight, and volume are premiums, are very attractive from a pollution-control viewpoint. Automobiles designated primarily for short mileage use could operate on secondary batteries with recharging accomplished via commercial power during nonuse periods. Family and commercial unit electricity could be supplied with fuel cells operating on natural gas. These fuel cells could be combined with a natural-gas heating system to supply thermal energy to the units. Finally, the application of fuel cells or batteries to commercial transportation, via electrically driven land or sea systems, should be studied to determine the economic feasibility of these low-pollution systems.

## Superconductivity

A decade ago, a discovery was made in materials which has provided a basis for revolutionizing energy conversion and energy transmission processes. This discovery, referred to as high magnetic strength superconductivity, has led to materials having zero resistance, under extremely low temperatures, to electric currents. This, of course, leads to the design and construction of high electric current conductors and very high strength magnets. The use of these magnets has further led very efficient power generation schemes - either previously unavailable or of low efficiency. Superconductors were first applied to large bubble chambers for high energy physics. Now, in less than 10 years from discovery to application, superconductors are being applied to compact and efficient rotating generators and motors, under ground energy transmission, as well as one of the most promising of direct electrical power generation schemes, MHD. Both the rotating machines using superconductors as well as MHD will be discussed in more detail in the following paragraphs.

Considerable detail could be given on the other uses of superconductivity alluded to above - such as high-speed trains, energy storage, underground electrical power transmission, medical research, plus general industrial applications. However, only the electrical power generation applications will be discussed.

## Superconducting Rotating Machinery

The use of superconductors (instead of water-cooled copper) in electrical rotating machinery allows the increase of 10-100 times the current through a given area of conductor. This leads to a dramatic reduction in physical size, volume, and weight of rotating electrical machinery. Thus, one can either obtain a much smaller unit of fixed power or can produce 5-10 times more power for the same volume and weight of conventional machinery. Not only does this size advantage turn out to be of value for aircraft and ship power, but for commercial power as well — either steady-state (base load) or emergency (portable) power systems of multimegawatt capability. The additional advantages of high voltage (better for transmitting long distances) and high overload capability (intermittent power pulse demands) are some other attributes of this type of generator/motor.

In this area of superconducting rotating machinery, there have been programs sponsored by private industry and various governmental agencies to provide for engineering evaluations. The support for general superconducting technology has come from many governmental organizations and laboratories. This support has provided a strong basis for the rapid development of this area of power generation. But today, the technology is here. Machines do exist and the power levels, megawatts, and learning curves are rapidly growing as new goals are continuously being achieved.

For as this country doubles its power production capability in the next decade, the location, efficiency, and physical size of the power plants become increasingly important and costly. What advantages has the new area of superconducting electrical machinery? The answers are high efficiency, compactness, and lower costs - costs from power generation, plus fewer and more compact facilities.

## MHD Power Generation

A great leap forward would be to have a type of energy conversion which could directly extract large amounts of electrical power from a thermal energy source. Such a technique does exist. It is called magnetohydrodynamics or MHD.

MHD is an energy conversion process which directly generates power from a very hot gas while it is moving through a magnetic field. In general, the higher the temperature one can work with for energy extraction, the higher the efficiency of the process. The limitation is generally set by materials, which in rotating machinery is the very high stress caused by spinning at high speeds and at high temperatures. The MHD energy conversion process requires no moving parts, and thus, can be operated at a much higher temperature and efficiency than rotating machinery. Higher efficiency can then be equated to reduced pollution, better use of resources (conservation), and higher power per fixed unit leading to fewer plant sites.

The MHD process can be used with any thermal energy source, which is hot enough, to either couple directly with the energy source or to complement a conventional powerplant system. The thermal energy sources primarily being considered today are hydrocarbon fuels where the MHD system may increase the overall plant efficiency from 40 percent to 50-60 percent. This could result in a reduction of the thermal pollution by over 200 percent for the same electrical power output. In addition more efficient utilization of our limited natural resources would be possible.

The marriage of MHD with a nuclear energy source could also be realized in a number of ways — each of which requires high temperature reactors. The higher temperatures are essential to make the MHD conversion process work efficiently. Operating temperature of above 4000°F, for example, are required for direct coupling of MHD to a gaseous cooled reactor. By using regenerative techniques, cycle efficiencies of 60-70 percent are feasible for commercial MHD power generation. This represents a doubling of today's nuclear powerplant efficiencies and a reducing of thermal pollution by over 300 percent.

Today, development programs are considering MHD plus nuclear energy combinations for electrical power in space. Efficiencies for near-term systems are much lower, but still attractive, in order to provide long life and to use lower temperature reactors.

MHD power generation technology has been supported in the past mainly by the Department of Defense (DOD) and NASA, until recently when the Department of the Interior entered the support picture for commercial power. NASA's major emphasis has been on nuclear MHD systems, while DOD's has been on hydrocarbon-fueled (combustion driven) MHD for short time operation. The advantages of instant on-off of combustion-driven MHD systems make it very attractive for emergency power and other very high-level pulsed power uses. The startup and shutdown mechanisms for MHD do not involve the dynamic loading of many precision components, such as in conventional rotating machinery. MHD has the added advantage of becoming more efficient with a larger power size as well as higher temperatures.

The output of most MHD systems of interest is direct current power which could be directly used in applications, such as wind tunnels, metal refining, and chemical industry which require very large amounts of power over short time periods. (Short times may range from millisecond pulses to running times of seconds to minutes, perhaps even hours.) The technology is directly applicable to emergency power plants, portable megawatt (1000 kW) units with fast, online responses and minimal water and air pollution systems. The attractiveness of portable power units, each modeled to a particular application, exists. MHD would provide not only a new capability in today's modern society, but the drastic lowering of thermal, air, and solid pollution coupled with resource conservation. This area of pulsed MHD power can differ significantly from commercial baseload MHD power, where economics still dominate the choice. However, as the pulses become longer the two will approach common technological goals, areas of development, and technological problems.

An obvious question is the cost per kilowatt — in fact, does it cost more for MHD units than conventional power? But what is really meant by costs? If you mean dollars per unit of electricity, the answer may be yes for the early MHD plants, because of the development required. However, costs must not only be gaged in economics. To many of us it costs dearly to add more thermal and air pollution; to waste valuable needed land for less efficient (more real estate) power plants; when a 50-percent increase in electricity could be obtained from each pound of fuel but is not being accomplished!

In summary, since the MHD process can work at much higher temperatures, and since the process eliminates a complete step in the direct conversion of thermal energy to electricity, MHD power systems should indeed by considered a 21st century energy conversion process that is available today!

## Conclusion

The necessity for compact, efficient energy sources for aerospace vehicles has led to the development of high performance energy generation, conversion, and storage systems. Because of their unique operating characteristics, these systems could be applied to significantly reduce air, thermal, noise, and waste pollution, which are generated during the commercial and private production and consumption of useful energy. Some of these applications have been discussed in this paper; hopefully more can be found.

The staggering ecological problems caused by our energy utilization necessitate the use of the very best technology to reduce this effect. Fortunately, this technology can be made available as a result of pioneering aerospace programs.

# CONTRIBUTIONS FROM SPACE TECHNOLOGY TO CENTRAL POWER GENERATION

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## Abstract

This paper discusses the central power crisis, and the present and relatively near-time contributions that aerospace technology is making to help solve this crisis. The principal emphasis is placed on the prospects of aerospace-derived magnetohydrodynamic (MHD) large-scale power generation. The strides that the Soviet Union is making in this field with the startup of the new U-25 plant near Moscow, having a total power capability of 75 MW, are reviewed. A much smaller program in the U.S. is outlined, and prospects of future benefits are discussed.

## Acknowledgments

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The existence of an energy crisis became an officially recognized fact with the June 6, 1971, release of the President's message on this subject to Congress. This crisis arises from a combination of factors, chiefly our civilization's insatiable requirements for energy, and the sudden realization that the very production of this energy is destroying the environment. One of the primary causes of our problems stems from central power generation where approximately 20 percent of the ground-based air pollution, and most of the thermal pollution, arises.

This country has spent a vast portion of its technical resources in the development of energy based on the fission of uranium. We now discover that this energy source is not backed by sufficient low-cost uranium reserves to make it economically feasible past 1985 [1]. The tardy development of the breeder reactor is delaying its installation to such an extent that it will be 1995 before an appreciable number of these devices can be put on the line and 2030 before a large portion of the power can be supplied by breeder technology. Some eventual solution may come from fusion plants, but the source of power has not even been demonstrated in a sustained reaction and, hence, stands from the viewpoint of developing technology where fission power stood in 1939. The time required for central power development is illustrated when one recognizes that only about 1 percent of our power is currently produced from fission reactors some 30 years after sustained fission reactions were first demonstrated.

We also face the possibility that the public will not accept the risks presented by fission reactors and later, the more dangerous breeder reactors. Recent evidence of this fact appeared on August 28 of this year when the U.S. Court of Appeals decided that the Atomic Energy Commission had failed to implement environmental safeguards in the construction of 68 nuclear power plants.

The technical approach to improve central power technology has been extremely one-sided in the U. S., concentrating almost exclusively on fission power, which is simply an energy source, and completely neglecting the process of converting energy into electricity once it is formed. Thus, we find that the thermal efficiency of the fission reactor is about 32 percent and is even less than the 40 percent efficiency found in fossil-fuel-fired steam plants. The technology in both of these stems from the 19th century steam cycle, and the improvements that have taken place have been through the evolutionary process with very little thought being given to other methods of conversion. Improvements, in the steam cycle efficiency, progress at a rate of a fraction of a percent per year. The remarkable fact that electrical power had not risen in cost before the recent power crisis is because of the sizing effect, which allows marked economic savings in power cost as the size of power plant units increased from 250 kW to 1200 kW. Currently, technical difficulties being experienced with large units in the 1200-kW range indicate a temporary limit to an improved economy with increased size.

The only place one can look for the technology which may save the current power situation is in the past developments of aerospace technology where attempts have been made to investigate new forms of energy conversion, and where particular attention has been paid to high-temperature technology. In fact, it is through high-temperature technology that the most likely near-time benefits can be achieved, since the principal loss in overall central power plant efficiency arises in the heat cycle. The heat cycle in such plants is presently less than 40 percent efficient as compared to a boiler efficiency of 90 percent and electrical generator efficiency of 98 percent. Therefore, we see that little is to be gained in efficiency of other components than the heat cycle itself, and so we turn to this improvement to achieve our greatest advance.

The Carnot efficiency of a heat engine is given by

$$\eta = 1 - \frac{T_C}{T_H}$$

where

$T_H$ = the absolute temperature of the heat source

$T_C$ = the absolute temperature of the heat sink

to which heat is rejected.

In the central power plant $T_C$ is the temperature of available cooling water at the site and $T_H$ cannot exceed the highest obtainable combustion temperature, the adiabatic flame temperature.

Currently the temperature limitation for steam is about 1200° F and the limitation for gas turbines, though higher, is generally considered to be 2400° F. Unfortunately, gas turbines are also limited to fuels containing no contamination in the form of ash, as a small amount of ash will rapidly destroy the turbine. The limitation of gas turbines requires that they burn fuels that are not really economical in the central power plant. Also, the gas turbine must be of small size to avoid limitations in blade tip velocity. Their size is projected to a limit of 250-kW electrical output per unit.

Despite the limitation of turbines, which is likely to prevent their taking over a large portion of base load power generation, their value in peaking was demonstrated last summer when large numbers of them operating on long-duty cycles prevented power blackouts. A vast amount of the technology used in these gas turbines come from experience in air-breathing propulsion research and development. Such turbine generation units have a short delivery time of approximately 1 year as compared to the 5 to 7 years required for delivery of ordinary central power stations. Thus, installation of aerospace-derived hardware has allowed overstrained, conventional power systems to remain in operation and has been an important factor in avoiding what might have been a disastrous failure of power equipment in the eastern U. S.

We can thus obtain relatively high temperatures and its attendant benefits from gas turbines, but it is not possible to rely on them for baseload plants. As stated in the President's message of June 6, 1971, MHD is a possibility for aiding in pollution reduction and in the more efficient production of base power. The Office of Science and Technology in the White House has further projected $500 million to be spent in acquiring this MHD technology over the next 15 years. Through the Interior Department, the Federal Government is spending $2 million during the current fiscal year in this technology matched with additional funds from utilities. Such amounts of money are of little significance in the central power field where it is necessary to spend approximately $200 million to build a central power plant, but this amount will aid in the early development of this technology and represents a start of federally-funded development in the central power area. Previous to this time, MHD technology has been developed through funds furnished by NASA and the U. S. Air Force for aerospace applications.

Magnetohydrodynamic power generation is achieved when an easily ionized metal, such as potassium or cesium, is introduced into high-temperature combustion gas, which is expanded to a high velocity through a nozzle and then directed into a magnetic field with properly arranged electrodes and external circuit. In this situation a moving conductor is cutting magnetic-field lines and a useful emf is generated. Although this kind of electrical configuration was described by Faraday over 100 years ago and was one of the first generator configurations invented, the problems associated with high temperature have prevented its application to high-temperature gas until recently. Through the use of current high-temperature, space-oriented technology and some 10 years of research and development in MHD, the state of the art has reached the point such that 10 more years of work can produce large power plants in the 2000-MW range size for practical use. The impetus for developing such plants lies in the high thermal efficiency between 50 and 60 percent, as compared to 40 percent for conventional fossil fuel and 32 percent for nuclear power plants. This makes MHD-type steam plants attractive from the standpoint of economics, thermal pollution, and air pollution.

The bar graph in Figure 1 shows the temperature range used in the ideal steam cycle, as compared to the range of temperature actually available. It is seen from this that the steam cycle uses only a relatively small portion of the available temperature range, and it is apparent that a much more efficient cycle might operate by topping the steam cycle with a device that could operate at the flame temperature or above.

In the MHD cycle an increase in flame temperature is necessary to produce the required electrical conductivity, and thus, the MHD generator uses regeneratively preheated inlet air. The bar graph showing the MHD operating range is illustrated in Figure 2. The MHD generator cycle is thus a true topping cycle since it does not use any portion of the temperature range of the conventional steam plant.

A simplified schematic diagram of the MHD-topped steam plant is shown in Figure 3. In this figure, a high temperature combustor is fed with coal, char, oil or combustion gas, preheated air, and a seed compound containing the easily ionized metal. The combination of high temperature and easily ionized metal produces the conducting combustion gas needed in the MHD generator. The conditions in these combustors are similar to those met in rocket engines. The conditions in the generator are near to those found in rocket nozzles, hence, much of the technology being used here has been developed in the space program. MHD generators of contemporary design generate dc current and therefore, an inverter must be used if we wish an alternating current output. From the generator section the combustion gas passes through a regenerative preheater required, as previously described, to produce the high temperature needed in the combustor for conductivity. High pressure air at approximately 5 atm is needed in the preheater combustor and generator so that the compressor work here has to be subtracted from the energy produced by the MHD generator section.

From the preheater the gas enters a steam boiler, but this boiler must be of a design that differs from that of the conventional boiler. In the conventional boiler, much of the heat transfer occurs through radiation. In this case, nearly all the heat transfer will be through convection and, in addition, the boiler materials must stand up to relatively high temperatures and the alkali metal seed that is present in the flow. The associated steam equipment is conventional in nature as is, of course, the alternator connected to it. This conventional power generating stage will supply 50 percent of the power or less.

Within recent years in the U.S., there has been literally no central power MHD program other than the small efforts which could be maintained in industries and the universities using their own funds to work on central power on the side. The vast majority of the work has been in basic research on basic phenomena and development work for the Defense Department. During 1971, funds have become available to start a minimal amount of central power MHD work. This is being largely funded by the Office of Coal Research, in cooperation with power companies. The largest such effort is under a contract let to AVCO and a group of utility companies to work on clean-fuel peaking plants, with a small amount of coal burning included. This contract is of the magnitude of $1.5 million to be spent over 3 years. Additional amounts would come from AVCO and the associated utilities. The next largest contract is with The University of Tennessee Space Institute, with $350 000 to be spent over 1 year on power generation with coal and char fuels. This work includes a small investigation of chemical regeneration. The Office of Coal Research is furnishing $264 000, $50 000 by the Tennessee Valley Authority, and $35 000 by the university. It is expected that a contract for approximately $100 000 per year will be let to The Massachusetts Institute of Technology (MIT) to perform some basic research studies, and to advise the Electrical Research Council on MHD work to be carried out by the power industry and the Office of Coal Research. In addition to this, STD Corporation of Los Angeles may receive approximately $90 000 to direct and operate a master computer program designed for MHD power system analysis. At Stanford University, there will be a research program funded by the Electric Research Council and the Bureau of Mines.

Stanford, The University of Tennessee Space Institute, and AVCO have a long history of continuous research and development on open-cycle MHD power generation and have additional MHD open-cycle work funded from other sources. The total central power program in the U.S. is inadequate to make appreciable progress in this area, but there is the anticipation that additional money will be available in the FY 1972 appropriation by Congress and from the Electric Research Council. The participants in the initial program have plans for such expansion when the resources are made available.

The situation, with respect to this technology, is quite different in the Soviet Union as an announcement of spectacular results was made in Moscow at the 24th Party Conference in March 1971, that a new kind of power plant was in operation on the Moscow power network. This plant is the U-25, whose prospective design was described in the August 1969 issue of Mechanical Engineering [2, 3, 4, 5]. Conjecture in the U.S. had commonly speculated that this plant would begin operation somewhere around November 1971, so it appears to be ahead of our original estimates. We believe that the plant is complete except for the steam turbine of the bottoming unit which would be of no importance in the experimental plant. Figure 4 indicates somewhat the size of the experimental installation, showing the generator diffuser, downstream heat exchanger, and exhaust cleanup and seed recovery tower. The exterior air preheaters, currently consisting of aluminum oxide, are heated by natural gas and then used to heat the incoming air. The heaters will be cycled periodically to provide a continuous flow of air at 1200° C. Such preheat is necessary in the MHD cycle in order to make the combustion products conducting. In the U-25 additional temperature is gained through the addition of a small amount of pure oxygen preheated at 1200° C to the air. The preheaters have been in operation for some time, though it is not completely clear how long they have been operated. Others at the High Temperature Institute have been cycled for 8000 hours. We have not seen photographs of the combustion chamber but one would expect that it is drastically smaller than the combustion chambers used with conventional power plants of the same size, because of the high temperature and pressure.

It is interesting to speculate on the rationale behind this approach by the High Temperature Institure to develop MHD central power technology. The approach is all the more interesting since no large-scale development in nonnuclear power plants has been undertaken before. In general, rather than a revolutionary approach, power technology has crept up slowly year by year to higher powers (13 MW) with slightly increasing efficiency. In Professor Scheindlin's method a gigantic experimental breadboard has been constructed. The power plant components are widely separated and housed in a large building which is so devised that experimental changes can be made with ease. Because of the problem of radioactivity, it is not possible to develop nuclear power along these lines, but MHD suffers from no such limitations, and the breadboard approach will give the Soviet Union an optimum experimental program. The question, for example, most frequently asked is, "What is the optimum channel design for the MHD generator, and what is its capability of endurance?" The U-25 is so designed that a number of trial channels can be placed within its magnet and tried in succession. We believe that such channels have already been constructed with cold-wall design, hot-wall design, and intermediate-wall temperature. The only photograph that we have seen of these devices was the corner of such a channel shown in a motion picture. It appeared to be a steep, diagonal wall design with relatively large insulator spacing. We expect that in addition to the diagonal wall electrical design, Faraday and Hall channels will be tried as well, so that in the near future the High Temperature Institute will have information on which channel works best. Not only is the MHD channel removable in this setup but other components are as well. We expect that at some time the conventional magnet will be replaced by a superconducting magnet. We have been told that the seed removal and exhaust cleanup device has been used at some other location. We were also informed that the performance of the preheaters was not satisfactory, and some improvements will be made in this device.

We have been told that there are 1000 people at work on this MHD project alone, and we believe that the project itself is skillfully and intelligently organized so that the Soviet Union will acquire the necessary technology for central power in a short period of time, at an optimum cost. We know that this plant is in operation and producing data. Questions of endurance and electrical efficiency will be solved in good time, and the High Temperature Institute should be congratulated on its ability to put such a plant in operation so soon. In the U.S., because of cost limitation, we are at least 5 years away from a plant of this type. Cost estimates of U-25 hardware range from $45 to $60 million for comparable construction cost in the U.S.

The yearly savings in the nation's power bill, if MHD fossil fuel plants were installed beginning in 1985, instead of ordinary fossil fuel plants, is shown in Figure 5. The upper curve represents the savings to be realized if fossil fuel takes over completely from nuclear fuel in 1985, and the lower curve indicates the savings if the split between nuclear and fossil fuel power generation is as anticipated from the usual power demand curves. If MHD central power plants of 55 percent efficiency are developed, one would expect the savings in the power bill to lie somewhere between these two curves. The competition might very well be effective in lowering the cost of nuclear power as well. It is assumed in making these cost estimates that $SO_2$ is virtually eliminated from the MHD exhaust, regardless of the type coal burned, because of the seed recovery process.

The future of central power is cloudy with the uranium supply and price difficult to forecast, the breeder reactor is uncertain in its development time and acceptance by the public, the conventional fossil fuel plant now, asymptotically approaching its highest efficiency, and with the cost of power plant construction steeply rising along with the price of fossil fuel. All of these conditions make the future of central power in the U.S. uncertain and predictions exceedingly difficult. It does seem clear, however, that MHD fossil fuel power generation, if acquired, would do several important things. It will provide economic competition for the nuclear system, give a possible alternative for relatively pollution-free power production if the breeder reactor fails to gain public acceptance, and extend the lifetime of our coal reserves.

There are numerous contributions that the space program has made to all of technology which are difficult to document. This is especially true in the central power situation. The utilities are the least advanced group in all of American industry. As a matter of fact, they have, among their employees, the smallest portion of Ph.D.'s found in any subdivision in large American industry. In 1968, for example, statistics show that the entire utility industry employed only eight Ph.D.'s, whereas the average for an industry this size in the U.S. would be 590 [7]. It has thus been very difficult to get utilization of advanced technologies into applications for the utility field. There is evidence that this situation is changing for the better, and we find that certain topics of advanced technology are under study by utility organizations. There is hope of future utilization of advanced technologies by the utilities to avoid the impending disaster in the energy field.

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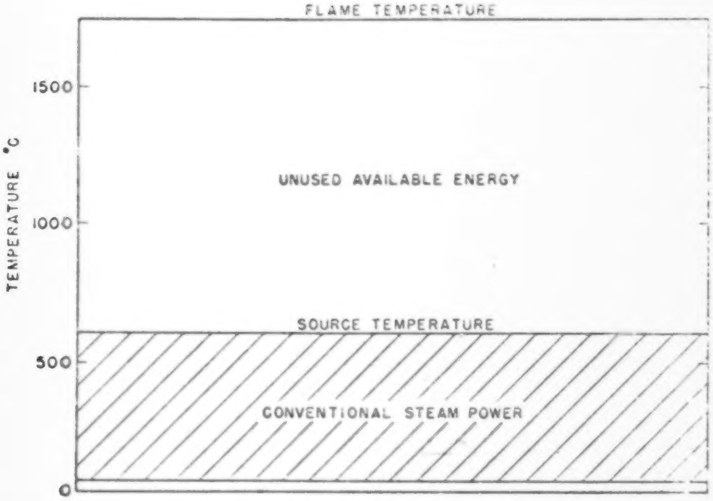
FLAME TEMPERATURE
1500
UNUSED AVAILABLE ENERGY
1000
TEMPERATURE °C
SOURCE TEMPERATURE
500
CONVENTIONAL STEAM POWER
0

Figure 1. Temperature range comparison.

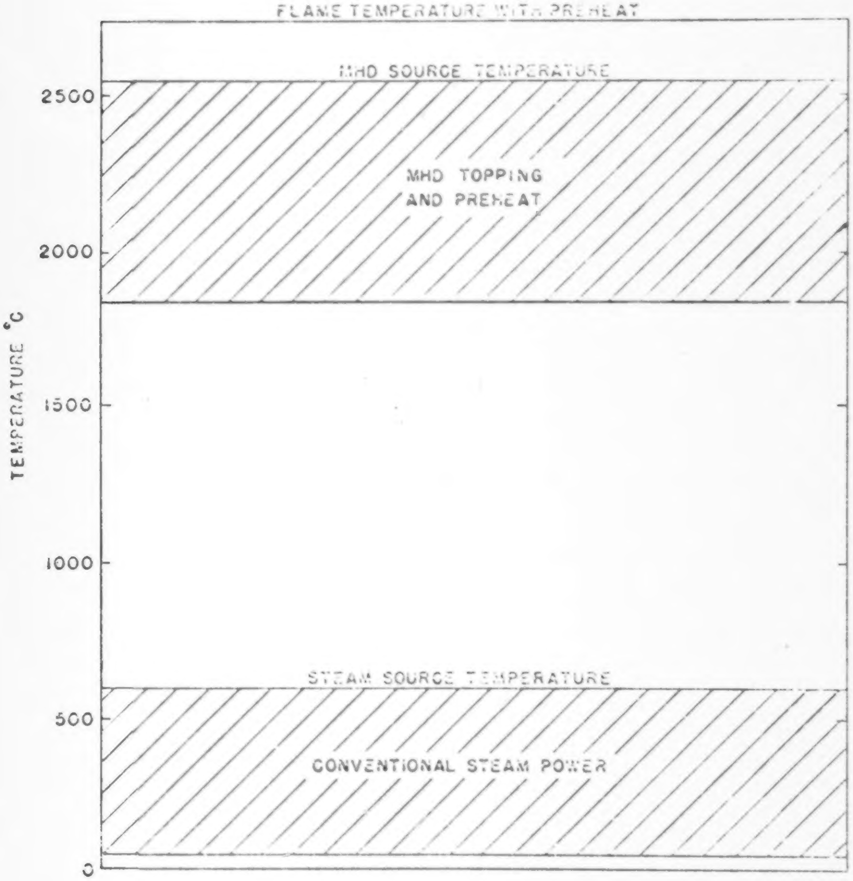
FLAME TEMPERATURE WITH PREHEAT
MHD SOURCE TEMPERATURE
2500
MHD TOPPING
AND PREHEAT
2000
TEMPERATURE °C
1500
1000
STEAM SOURCE TEMPERATURE
500
CONVENTIONAL STEAM POWER
0

Figure 2. MHD operating range.

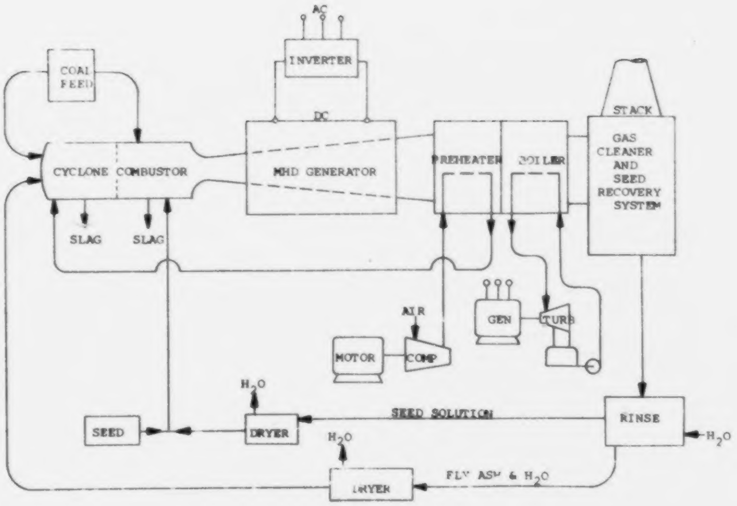
AC
INVERTER
DC
COAL FEED
CYCLONE COMBUSTOR
MHD GENERATOR
PREHEATER
BOILER
STACK
GAS CLEANER AND SEED RECOVERY SYSTEM
SLAG
SLAG
AIR
GEN
TURB
MOTOR
COMP
$H_2O$
SEED
DRYER
SEED SOLUTION
RINSE
$H_2O$
$H_2O$
DRYER
FLY ASH & $H_2O$

Figure 3. MHD-topped steam plant.

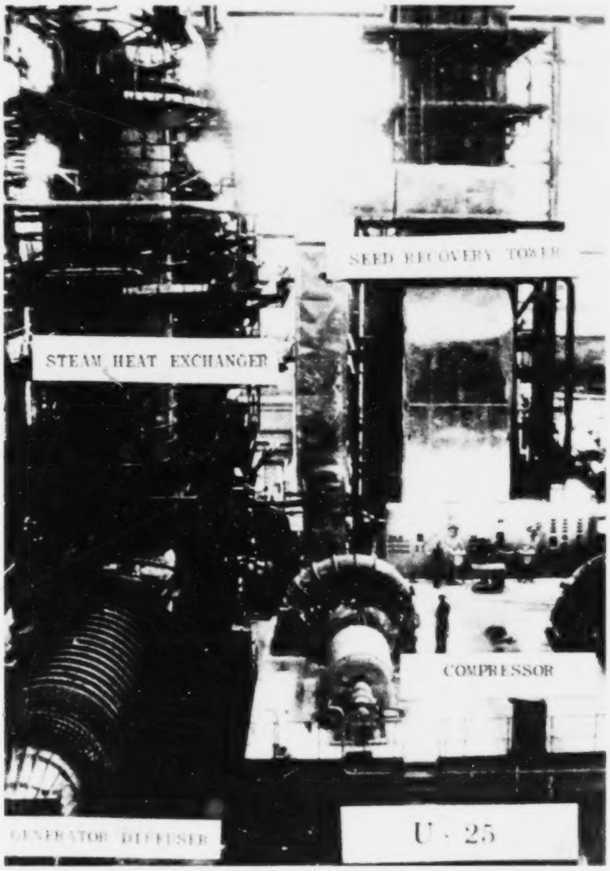
SEED RECOVERY TOWER
STEAM HEAT EXCHANGER
COMPRESSOR
GENERATOR DIFFUSER
U - 25

Figure 4. U-25 power plant.

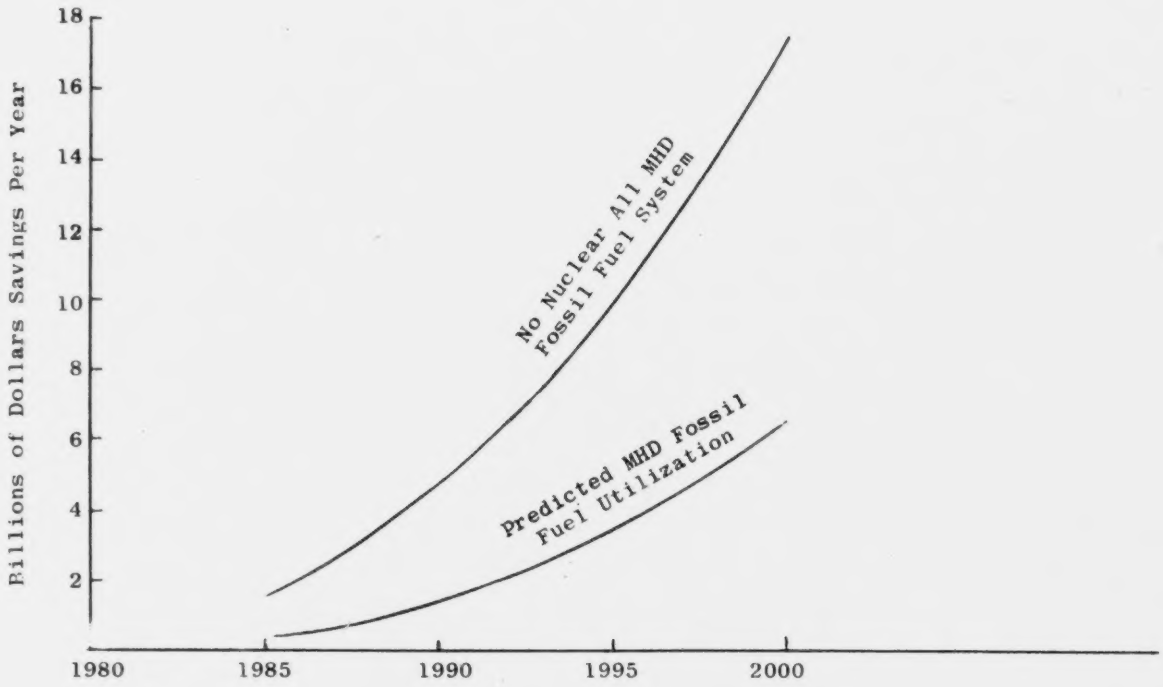

Figure 5. Savings each year that might be achieved through MHD technology on total cost of central power in the U.S.

# SOLAR ENERGY, ITS CONVERSION AND UTILIZATION

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## Abstract

This paper describes the work being carried out at the University of Florida Solar Energy and Energy Conversion Laboratory in converting solar energy, our only income, into other needed and useful forms of energy. A treatment such as this demonstrates, in proper perspective, how solar energy can benefit mankind with its many problems of shortages and pollution.

The paper will be conducted like a tour through the laboratory, describing the conversion processes, equipment, and performance. The testing of materials; solar water heating; space heating; cooking and baking; solar distillation; refrigeration and air-conditioning; work with the solar furnace; conversion to mechanical power; hot air engines; solar-heated sewage digestion; conversion to electricity; and other devices will be discussed.

## Acknowledgments

The Solar Energy and Energy Conversion Laboratory of the University of Florida was used as a basis for this paper, but credit must be given to the many laboratories around the world and individuals who are engaged in the effort to utilize solar energy for the betterment of mankind. Their work supports ours through ideas and results as our work is helpful to them.

Thanks must be given to the faculty, students, and staff of our laboratory who have, over the years, had an important part in advancing the state of the art of solar energy utilization. They have also provided knowledge and results for others to build on.

## Introduction

The widespread concern with our energy situation and crisis, and what meeting the ever-increasing demand of this energy does to the environment through pollution, prompted the writing of this paper. It presents the overall activities of the Solar Energy and Energy Conversion Laboratory of the University of Florida rather than the technical details of one particular investigation.

The laboratory has looked into old methods of converting solar energy into the forms of energy needed, has used the present state of the art, and has pioneered in many areas of solar energy utilization.

Before going into the various programs and efforts to utilize solar energy, the reasons for the great interest in this field should be presented.

It is obvious from all surveys and reports that we are using our fossil fuels at a tremendous and ever-increasing rate so that, in the not-too-distant future, these supplies of energy, so vital to our present growth of civilization, will be depleted. For this reason, it is of utmost importance that we look for other more permanent sources of energy and learn to use them before the dire need arises. Solar energy is readily available; well distributed; inexhaustible, for all practical purposes; and has no pollution effects upon the environment when converted and utilized.

Our present usage of energy can be compared to a family or group living off their savings, stored in a bank, and being steadily depleted. This process cannot go on very long unless some income is added to the savings.

In the field of energy the most abundant income is solar energy. This incoming energy was, usually in very inefficient processes and over millions of years, converted into our fossil fuels. With these savings rapidly disappearing, we will have to learn to use this income, in the form of radiant energy, directly, by converting it into the forms of energy needed.

This conversion from solar energy into the desired forms should be done in the fewest possible steps and along the most direct route. This procedure will insure the most efficient way of doing this and will keep the necessary equipment simplest.

Solar energy has certain characteristics. It is intermittent, only available during the day on a particular location on the surface of the earth. In spectral character, it approximates a blackbody source of about 10 000 ° F, modified by gaseous layers of both the sun and the earth' s atmosphere.

It arrives on the surface of the earth both as direct radiation and diffuse radiation. The former portion can be concentrated if desirable.

A knowledge of the specific properties of materials under solar irradiation will then allow the collection and/or concentration and absorption of this energy.

If nighttime operation or operation during bad weather conditions is necessary or desirable, the storage has to be provided. For many applications, this is not necessary. The energy could be stored in a conventional manner as potential energy (pumped water, etc.); as heat in hot water storage tanks or rock bins; as chemical energy utilizing chemical processes, the latent heat or heat of fusion; etc.

In other words, the technology has been developed to convert and utilize solar energy, but the economics and sociologial acceptance has still to be worked out in many cases. These problems vary from region to region and therefore take on a local character to be worked out by the potential users.

To be most effective, local materials should be used in fabricating by local methods and labor fitting the economics and habits of the local civilization.

With this introduction of a general nature, the paper will now go into some of the work done by one group. The best way to do this is to take you on a tour through the Solar Energy Laboratory of the University of Florida.

## UF Solar Energy Laboratory

The University of Florida Solar Energy Laboratory is one of the largest laboratories of this kind, and a tour through it will give an idea what such laboratories look like and the kind of work which is carried out in them. The work carried out at this laboratory is supported by work and persons all over the world, and proper credit should be given to them.

Figure 1 presents the entrance, within the gate to the laboratory, and two of the four buildings.

Stepping around these two buildings one can see some of the laboratory equipment, which will be discussed in more detail in the paper and the following illustrations. Figure 2 shows this equipment with engines of various types in the foreground and behind them are collectors and concentrators of various types. On the left of the picture are a small solar air-conditioning system and two solar water heaters, and a solar still and parabolic concentrators. Further visible are a solar power plant, a solar still, the solar furnace and solar calorimeter to investigate the solar properties of materials. In the background, partially visible, is a 5-ton solar air-conditioning equipment.

## Solar Properties of Materials

The first step in utilizing solar energy is to find materials which will withstand the exposure necessary in the equipment to be built. To do this, we take some of these materials and expose them under rather realistic operating conditions to the weather and the sun. Figure 3 shows different plastics exposed to the environment, stretched over cans which are filled with water or sand or wet soil, etc. If these materials deteriorate after a short time the investigation is terminated.

Those materials which, however, withstand this exposure test satisfactorily are then investigated in our Solar Calorimeter, as to their reflection, absorption, and transmission characteristics under actual solar irradiation (Fig. 4).

The Solar Calorimeter can be oriented into any desired position, it can be made to follow the sun, it can simulate severe winter conditions or extreme summer environments. It is further instrumented with many, many thermocouples to be able to obtain complete heat balances. This instrument, the only one of its kind, is constantly used to investigate new types of materials, such as glasses with tinting or coatings, laminated glasses and plastic materials, venetian blinds, thermopane windows, plastic bubbles for aircraft, fabric used for clothing, curtains and draperies, water-cooled venetian blinds, etc.

With the properties determined a selection can be made to obtain the best results in any desired application.

## Solar Water Heating

In Figure 5, five different flat plate collectors used for water heating are presented. They consist of a box with glass or plastic covers (one or more) with a metallic absorber element inside, which contains the water. This water is circulated to the small water storage tanks shown above. These absorbers can be compared with each other when exposed to the sun under identical conditions and for the same length of time.

Some of the absorbers have copper plates with copper tubes soldered onto them; others are two flat plates riveted, crimped, or welded together. The most efficient unit found consisted of two thin flat copper plates fastened together on the edges and providing a water space of about 0.25 in., with one glass cover and 1 in. of Styrofoam insulation behind the plates. No plastic materials were found to be as good as glass since none of the ones we could find had the characteristics of glass – namely, letting through the short-wave radiation but not the long-wave radiation. This characteristic of glass allows it to be used in the design of a solar trap.

Figure 6 presents a typical Florida Solar Water Heater. It consists of a sheet metal box, 4 ft by 12 ft, covered by a layer of glass. Inside the box is a copper sheet with copper tubes soldered to it in sinusoidal configuration and connected to an 80-gal water storage tank. This system, rather common, is found satisfactory for a typical American family of four with an automatic washing machine, etc. Under the copper sheet is 1 in. of Styrofoam insulation. For satisfactory operation, the bottom of the hot water storage tank must be above the top of the absorber to provide circulation without a pump.

Figure 7 shows actual installations of this type in an apartment house in Florida with each apartment having its own unit to provide the needed hot water.

These standard units may be damaged if used in freezing temperatures, and for this reason, we developed a dual circulation system which eliminates this problem. It consists of two tanks, one inside the other, the outer tank being connected to the collector. This system is filled with an antifreeze solution. The heat is then transferred from this solution and through the wall of the inner tank to the water to be used. Since in this system the primary circuit operates at atmospheric conditions (the outer tank can just have a lid on it) the collector can be constructed much cheaper and lighter, for example, patterned after the most efficient design mentioned earlier. Insulation covers the outside tanks.

## Swimming Pool Heating

Another type of heater which has interested many in Florida is a swimming pool heater, as shown in Figure 8. It is one of the simplest ones and least expensive. It consists of a galvanized sheet wrapped into plastic. The sheet is painted black (flat) like all the other absorbers. Water from the pool can be fed to these by the filter pump and then running down the front and back of the metal plate, drains back into the pool. It usually takes a collecting surface equal to the pool surface for raising the water temperature in the pool 2° F. These absorbers can be constructed to form the fence around the pool, which is in many localities required by law, and, in addition, can provide privacy.

## House Heating

If the objective is to heat a house rather than the water, it can be done by hot water circulated through baseboard pipes in a conventional hot-water heating system. However, frequently, it is more convenient or desirable to heat a building by hot air. Figure 9 shows such an air heater, made up of overlapping aluminum plates, painted black on the portion exposed to the sun. About one-third of each plate is showing; the other two-thirds is shaded by the plate above. They are put into a glass-covered box. The air will enter this unit on the bottom and then, streaming between the hot plates, will pick up the heat and leave on top as hot air. The circulation can be produced either by free or natural circulation or by a fan.

All the above-mentioned collectors are ideally facing the south and inclined with the horizontal at an angle equal to the local geographic latitude, plus 10 deg. This gives a little higher collection efficiency during the winter when the days are shorter.

The air heater could be designed forming the wall of a building, let us say the east wall where it could produce hot air the first thing in the morning, to take the chill out of the building.

## Solar Cooking

Another application can be a solar oven, essentially a glass-covered box facing into the sun. Cooking and baking temperatures can easily be reached with such a device (Fig. 10). Periodic (about every 15 min) reorientation, because of the movement of the sun, is required. Flaps can be added (Fig. 11) to provide some degree of concentration and, thus, bringing the things to be cooked up to temperature quicker. Very little heat is actually required for the cooking process, only a certain temperature for the required length of time. If one of these ovens is to be used in the late afternoon or early evening, the walls could be made thick of clay or other materials which can store appreciable amounts of heat and thus remain warm long after the sun has gone down.

## Solar Distillation

One of the major problems in many parts of the world is fresh water. With very simple equipment, solar energy can convert salt or brackish water into fresh and pure water. Figure 12 shows a simple solar still, a metal box with slanting glass facing south. Inside the box is a pan on short legs, painted black and holding the bad water. The sun shining into this pan heats the water and vaporizes it. The vapor or steam then will, when coming in contact with the cold surfaces of the box, both the glass and the metal, condense, forming the fresh water which runs down the sides in the form of droplets. This fresh water can then be collected for future use. About 0.5 lb of water can be produced at an average per square foot, per day.

Another larger still is shown in Figure 13. The pan is covered by glass at about 45 deg, which forms most of the condensing surface. Glass is much better than plastic since it forms film condensation, letting the solar energy through without much difficulty. Plastics, in general, produce dropwise condensation, each droplet forming a little crystal which reflects much of the incident solar energy. This larger still is also designed to be able to collect rainwater and, in some areas such as Florida, this can double the output of the still.

The best orientation of the still depends somewhat upon the angles of the glass but is generally east-west or somewhat northeast-southwest.

## Solar Refrigeration and Air-Conditioning

Another phase of our work is the use of solar energy for solar refrigeration and air-conditioning. At a number of international meetings it was pointed out that famine could be prevented in much of the world if the food, which is raised during certain parts of the year, could be preserved from spoilage, and thus preserved for use during the rest of the year. This requires refrigeration, and for remote areas, or areas without electricity, solar refrigeration may well be the answer.

Some of our early work along these lines was to heat oil to rather high temperatures by concentrating solar energy, and then circulating the hot oil around the generator of an ammonia absorption refrigeration system (Fig. 14). This picture is somewhat out of order since all the applications thus far dealt with solar energy in its natural state, without concentration, but it was put in here since it was actually our first attempt. We believe, however, that solar refrigeration without concentration holds much more promise since nonconcentrating devices can also utilize the diffuse portion of solar radiation, thus function even on cloudy days.

A number of small units have been built and then a 5-ton unit shown in Figure 15. Flat plate collectors heat water, which is then circulated to drive out the ammonia from the water in the generator of the system. This ammonia vapor is condensed and then expanded, providing the cooling effect by evaporation. After having done its work the ammonia vapor is reabsorbed in the ammonia absorber of the system into the water to repeat the cycle.

Figures 16 and 17 show a smaller version of such a system with some improvements. The main one, combining the solar collector and the ammonia generator into one unit, thus eliminates the primary fluid and reduces the heat losses by providing a more direct path for the solar heat to get into the system and do its work. On a good day this small 4- by 4-ft unit can produce 80 lb of ice.

It should be pointed out again that all the applications mentioned so far did not require concentration of solar energy, and therefore could utilize the diffuse portion of solar energy and even work on cloudy days.

The solar air-conditioning or refrigeration systems have an added advantage, that the demand and supply are in phase. When the sun shines hottest, the need for refrigeration and air-conditioning is greatest.

## Solar Energy Concentration

For some uses, however, higher temperatures than can be obtained with flat plate, nonconcentrating collectors are needed. If this is the case, then concentration is called for. Many different methods can be used for concentration, the simplest ones stationary in design but not as good, and the better ones requiring methods which allow them to follow the sun.

Figure 18 shows a simple high-temperature absorber. It consists of a number of parabolic troughs oriented horizontally and with a pipe running down the focal line of the parabolas. The system of parabolic troughs is inclined at about the local latitude. Depending upon the diameter of the pipe, adjustment may or may not be needed during the year. The solar energy is reflected by the parabolic surfaces upon the focal pipe, which is painted with a good absorbing paint (flat black), absorbs this energy, and transmits it to the fluid inside the pipe. This device can easily produce hot water, steam, or hot oil.

Some energy is lost during the early morning and the late afternoon hours with the above method of converting solar energy to heat because of shading, but the simplicity and stationary design have considerable advantages economically and do not need much attention.

## Solar Power Plant

If better efficiency is desired, then cylindrical parabolas, which are allowed to follow the sun, can be used. In the simplest form they can be made (Fig. 19) of a single parabola with a pipe at the focal line. This particular absorber is used to produce steam to operate a small steam engine, which in turn drives a small generator and lights up a light bulb, thus demonstrating what a solar power plant could look like. The 2- by 5-ft absorber is the equivalent of 500 watts of electrical heat.

A large cylindrical parabolic absorber is shown in Figure 20, having dimensions of 6 by 8 ft, with a glass-covered focal tube. The glass cover reduces the losses from the heated tube. Depending upon the needs, different diameter tubes can be used. Copper has been found best, again painted with a good absorbing high-temperature paint. This absorber is mounted on a rotating axis parallel to the earth axis. It is adjusted to face the east in the morning and then, by an electrically driven worm gear reduction unit, is made to follow the sun all day. Where electricity is not available, a heavy weight with a clockwork timing unit can be used as well. The construction of such a large device must be rather rigid, since wind loads in windy areas may make it difficult to keep the unit directly facing the sun and to keep it from oscillating.

This unit has been used to produce steam for the operation of a fractional horsepower steam engine, to provide 800°F oil to operate a solar refrigerator, etc.

Other methods of concentrating solar energy are lenses both of glass and other materials (including liquid lenses), but they are not widely used because of their cost in large sizes and their weight. However, Fresnel lenses, specially made from plastic sheets, with grooves cut or embossed so as to focus the rays, can be produced rather inexpensively, are unbreakable and can be of large size and light weight. The lens shown in Figure 21 is of this type, and can produce temperatures of 2000°F.

A very effective way of concentrating solar energy is to take flat pieces of reflecting materials (for better results, they can even be slightly curved), such as mirrors or reflecting metal surfaces, and oriented in such a manner as to reflect the solar radiation on one spot. Front surface reflecting mirrors are giving better performance than, for instance, back silvered mirrors, where some of the energy is absorbed in the glass. Very large concentrators of this type have been built with thousands of these mirrors used in some of the large solar furnaces in the world.

## Solar Cooking

A few concentrating panels of this type are shown in Figure 22, where three of them concentrated upon a board will make this board flash into fire. Such mirrors can also be set up in a different pattern like the one shown in Figure 23 where the mirrors are set up into a circular pattern, heating the fluid in the jar at the focal region of the device.

If higher concentration, and thus, higher temperatures, and smaller focal regions are desired, then either smaller mirrors are needed or continuously curved surfaces can be employed. In this manner excellent concentrating mirrors, even of optical quality, can be made but they are very expensive, and there is a practical limit to the size of these configurations.

Two such mirrors of fair quality are shown in Figure 24, the one on the left being strong enough to hold its shape by being properly formed and the one on the right being supported by ribs from wood, in this case, which are cut out forming parabolas. Then thin, highly reflecting metal sheets are held loosely to these ribs to allow for expansion when the metal sheets are slightly heated, thus avoiding distortion. This type of construction is especially important in large sizes, and was also used in the large parabolic cylindrical concentrator mentioned earlier.

The two concentrators (Fig. 24) were used as solar cookers where only a moderate amount of concentration is needed (too good a concentrator may burn holes into the containers used if great care is not taken). Therefore, not too good a quality is more desirable for this application.

If such concentrators are used for solar cooking, it may be desirable to design them for easy portability, thus either in sections which can be collapsed for moving, or of coated cloths of an umbrella design which can be folded when not in use. This type of an oven and a cooker of moderate concentration is shown in Figure 25. The flaps on the oven can be adjusted to regulate the degree of concentration needed. An oven of this design will shorten the cooking and baking time by bringing the food up to the desired temperature faster than the type mentioned earlier.

Higher concentration, that is, higher concentration than the surfaces previously discussed can provide, is needed for high-temperature work, solar engines, etc. For this purpose, the geometry has to be more perfect. Figure 26 shows various mirrors of rather high quality giving high degrees of concentration, with the ultimate reached in the solar furnace (Fig. 27).

## Solar Furnace

This solar furnance, with a 5-ft-diam mirror, can produce concentration ratios of almost 25 000 and temperatures of up to 7000 °F.

Solar furnaces can be used for research where high temperatures and extremely pure, uncontaminat heat are needed. Materials can be enclosed in glass containers or plastic containers, surrounded by vacuum or any desired atmosphere, and heated under very closely controlled conditions. Since the solar energy can be concentrated onto a very small region, it is not necessary for the support of the sample to be able to withstand very high temperatures nor is it necessary for the glass or plastic container to be high-temperature resistant since the energy, as it goes through this material, is not yet concentrated to a high degree (Figs. 28 and 29).

The furnace has been used to produce extremely high purity materials, to grow crystals of high-temperature materials – crystals nonexisting in nature, to extract water from rocks and moisture-containing soils (work which may be of great importance when a lunar station is going to be set up, since many experts believe that the solar furnace will be an important tool on the moon), and it may be possible to produce materials on location instead of hauling them from the earth to the moon. We received a citation from the Air Force for this work.

## Mechanical Power

One of the largest programs in our laboratory is the conversion of solar energy into mechanical power. This is done by steam engines, one of them shown in Figure 30 and supplied with steam from the large cylindrical parabolic concentrator (Fig. 31). The combination shown will give about 0.25 horsepower, only limited by the concentrator and quantity of steam delivered by it.

A working model of a steam power plant is shown in Figure 32, with the absorber and boiler shown from the front (Fig. 18), and the engine driving a generator and lighting up a small light bulb. A steam engine with a different type of absorber is also shown in Figure 33. The small square boiler in this case must be used with the concentrators shown in Figure 22. Other combinations and designs are possible and will work equally well, if designed properly.

We believe, however, that hot-air engines have a much greater promise than steam engines for fractional horsepower requirements. They are safer, quiet, and only need a source of heat, any source. These engines can be operated off solar energy during the day and, if power is needed during the night, by other sources of heat, such as wood, coal, oil, or it can be operated by the heat produced from the burning of waste products such as trash, cow dung, etc.

## Closed-Cycle Hot Air Engines

There are two basic types of hot-air engines. One is the closed-cycle type, which encloses a certain amount of air which can be pushed back and forth by a plunger between hot and cold surfaces. When the air is in contact with the hot surfaces, it is heated and thus increases the pressure in the engine. When in contact with the cold surfaces, it is cooled, thus decreasing the pressure in the engine. A power piston is pushed down when the pressure in the engine is high and returns because of flywheel action when the pressure is low. So every downstroke is a power stroke. With proper timing of the power piston and the plunger, considerable amounts of energy can be produced.

These engines are inherently slow-speed engines, a few hundred revolutions per minute, since it takes time to heat and cool the air. The heat transfer can be improved by either pressurizing the engine or filling it with gases, such as hydrogen or helium. Also, a large surface regenerator will increase the performance of such engines, but they become more complicated and much more expensive by such additions and refinements.

Figure 34 shows a quarter-horsepower engine with the displacement cylinder in a horizontal position on top and the power cylinder directly underneath in a vertical position. The blackened end of the displacement cylinder is heated and the other end cooled, in this case, by a water jacket. Figure 35 shows such an engine disassembled. The basic unit for this engine is a lawnmower engine, but the engine itself is much simpler and less expensive since it does not require any valves, carburetor, or electrical system.

Another engine (Fig. 36) is shown in operation with a radiation shield around the hot end of the displacement cylinder. The concentrated solar energy can clearly be seen heating the end of the displacement cylinder. A 5-ft mirror is used with this engine, which has to be moved about every 15 min to keep the energy concentrated on the engine. This movement is rather small and could be automated. Enough heat capacity is built into this engine so that if small clouds pass over the sun the engine will continue to operate.

These engines are not self-starting and after the engine surfaces are heated they must be given a push but will then take off on their own. This should be no handicap if compared with the attention a team of bull oxen requires. A single man can operate a bank of these small engines, adjusting the mirrors periodically. In addition, no further land is needed, as in the case when animals are used to raise the food they need.

Figure 37 shows another one of the closed-cycle hot air engines in operation. In Figure 38 it is pumping water out of a ditch. The mirror shown with this engine is actually much better than needed but was used since it is available. It is an old mirror from the solar furnace which has been polished so many times that the reflecting surface is no longer very good. For engine operation the concentrator only has to be good enough to provide a spot of concentration of the size of the displacement cylinder of the engine, about 3.5-in. diam, for the engine shown.

A one-half horsepower engine, closed cycle, is shown in Figure 39, which is designed to be used with solar energy and can directly, without modification, be used to burn wood, coal, or liquid fuels. If used with solar energy it is only necessary to open the big door shown and to concentrate the solar energy upon the end of the displacer cylinder inside the furnace box.

## Open-Cycle Hot Air Engines

The other type of hot air engines is of the open-cycle type (Fig. 40), which takes atmospheric air, compresses it, then heats it, again by solar energy or other means, expands the air and exhausts it into the open.

These engines have the advantage that the heating of the air and the speed of the engine are independent, therefore these engines can be made to run at much higher speed. This higher speed makes it possible to reduce the weight per unit power output, but the engines built by us so far do not have as high a conversion efficiency as the closed-cycle engines.

Both these types of hot air engines, but especially the closed-cycle type, can be built without special equipment and with only the simplest types of machine tools. The timing for best performance is rather critical and should be adjusted carefully. Another critical parameter of the closed-cycle engine is the clearance volume.

Our work was concentrated on fractional horsepower engines of the portable type which could be used for irrigation or drive small machinery.

There are other solar devices which can convert solar energy into mechanical energy but they are of less importance.

## Solar Pump

Figure 41 shows a solar pump model, in this case, made out of glass so that its operation can be observed. It only has two check valves and otherwise, no moving parts. A boiler is connected by a straight and a U-shaped tube to a chamber with check valves at the inlet and outlet. The liquid in the boiler is vaporized, pushing liquid out of the system, and when the vapor reaches the bottom of the U-tube, it suddenly streams into the other chamber filled with cold liquid, where the steam rapidly condenses. While the stream is produced, the top check valve is open and liquid is pushed out. When the vapor condenses the top check valve closes, because of the vacuum produced, and the bottom check valve opens, letting in more new liquid to be transported. This pulsating action can be smoothed into a steady flow if an air chamber is provided past the top check valve.

## Solar Turbine

Another method of converting solar energy into mechanical energy is by means of a turbine, a model of which is shown in Figure 42. A vertical chamber with a turbine wheel in it is filled with a volatile liquid to just above the turbine wheel. The collecting surface has a cover with a small hole in the bottom of the chamber. The liquid will drain through this hole into the space below, will come in contact with the hot surface below and vaporize. The vapor will stream upward forming a jet which in turn drives the turbine wheel. When leaving the turbine wheel it will come in contact with the cold surfaces of the upper part of the vertical chamber and condense, running down the walls and repeating the cycle.

For some applications it is more convenient to separate the steam generator from the turbine and the condenser.

## Solar-Gravity Motor

Shifting of weights from one side to the other on a wheel or seesaw can do work. Figure 43 shows a motor where a number of spheres, two at a time, are connected by a tube and mounted on a wheel. The sun shining on one side will vaporize the liquid, and the vapor streaming to the other side will condense. If properly designed, continuous motion can be obtained, which can be used to pump water or do other useful work. The conversion efficiency and power output are rather small but may be sufficient for certain tasks.

## Solar Thermo-Phase Shift Reciprocating Engine

Figure 44 shows another device for the conversion of solar energy into mechanical energy. It consists essentially of a column of water with bellows at the top. The system is completely purged of air. The end of the tube is heated by concentrating solar energy upon it or any other concentrated source of heat. This will vaporize the water on the end of the tube and force the column of water to the right, as shown in the picture. With vapor now in contact with the hot surface, the heat transfer is suddenly decreased tremendously, and so, the cooling effects are now greater than the heating. The vapor condenses, letting the column of water return to the left until it touches the hot end, and the cycle repeats. Cooling of the lower end of the column of water will improve the performance. The moving column will make the end of the bellows move back and forth. By coupling to a flywheel, this reciprocating motion may be transformed into rotary motion. This very simple little device is quite noisy, sounding like a small gasoline engine and can, by adjusting the pressure on the end of the bellows, be made to run at different speeds, several hundred cycles per minute if desired.

## Conversion to Electricity

If electricity is desired as the form of energy to be used, it can be produced by converting solar energy into mechanical energy and then driving a conventional electric generator. The solar energy can be converted more conveniently directly into electricity by one of the many solid-state devices, normally referred to as solar cells. Through the space program great strides have been made in the photogalvanic conversion field utilizing silicon as the most common material. Two photogalvanic converters are shown in Figures 45 and 46.

Thermoelectric conversion has also been investigated in our laboratory, using certain semiconductor materials as superthermocouples as well as thermionic conversion, but not a great deal of energy was spent in these areas.

## Sewage Treatment

Another project of interest is application of solar energy to sewage treatment. One phase of this work provided solar heating for sewage digesters. By heating these digesters and controlling the temperature for optimum efficiency, considerably more sewage can be handled by a given size plant. Many plants buy expensive covers ($30 000 and more for not a very big one) and collect the sewage gas and then burn it to heat the fluid in the digesters. Many of these plants even buy fuel, and all of this becomes a very expensive operation. Solar heating of these digesters proved relatively inexpensive by being able to use plastic sheets glued together to form an air-mattress-type cover floated on top of the digester. This, in many cases, provided enough of a solar trap to keep the digester at good operating temperatures in our region. As a matter of fact, in one winter with rather severe and prolonged freezes, all the bacteria in the unheated digesters died and action stopped completely until they were restocked. During this same period the solar-heated digesters survived, and the bacterial action, even though slowed down during the extreme cold spells, picked right up again when the temperature of the digesters increased. The basic problem of heating here is the same as for swimming pools (Fig. 47).

If the digester is designed more like a solar still, in addition to the digestion, fresh water can be produced by distillation and the remaining sludge used for fertilization.

## Conclusion

The above discussion is provided with a number of illustrations because we believe that pictures can tell a story much better, covers much of our work, but by no means all of it. It presents the range of activities in our laboratory.

When solar energy utilization is contemplated, its availability and amount of supply, the requirements, the availability of materials and labor, as well as economic considerations should be analyzed on a regional or local basis, since large variations can occur from place to place on a global scale. The devices discussed and shown here may have different degrees of applicability in different areas.

We recommended one time, as an example, for an Army post in Chile to spread steel pipes on the sandy ground and to hook them together into a number of parallel circuits to provide the hot water they needed; they had the steel pipe, the labor and the sandy land. To recommend the Florida-type solar water heater would have been the wrong thing to do since they did not have copper sheets, copper pipes, and hot water storage tanks. Their problem was solved with local materials under local conditions and produced the required results.

In closing, I would like to say that solar energy, its conversion and utilization, will not solve all our problems, but it will be a great step in the right direction, by supplying needed energy wherever it can without having adverse effects upon the environment and, at the same time, conserving our fossil fuels, which can do much more for us than provide heat. The chemicals they contain can be used as preservatives, in medication, etc., so that the indiscriminate use of these resources for energy is unwise and a loss to future generations.

Figure 1. Entrance to University of Florida Solar Energy Laboratory.

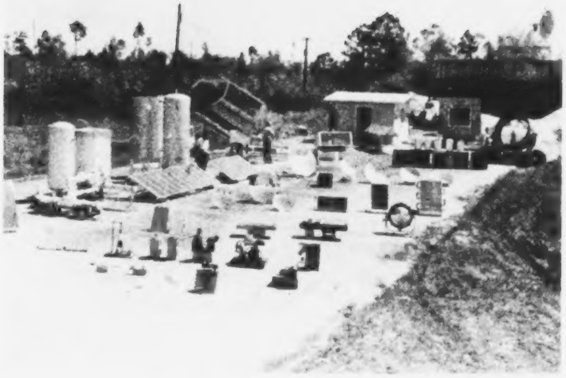


Figure 2. View of some of the solar energy conversion equipment in the laboratory.

Figure 3. Exposure test of some plastic films.

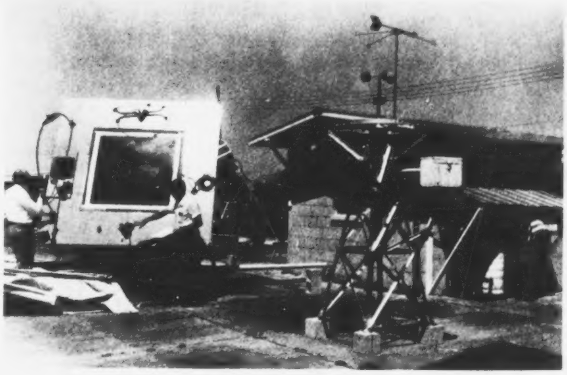


Figure 4. Solar Calorimeter.

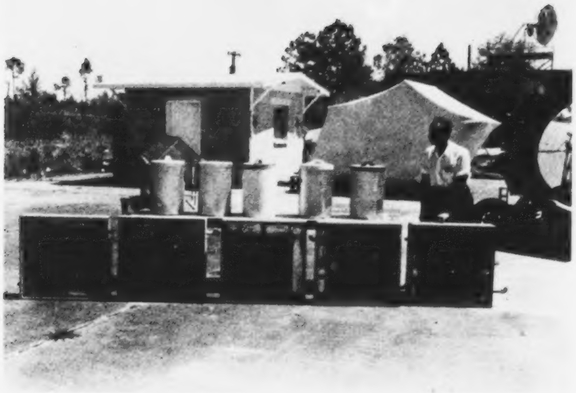


Figure 5. Experimental flat plate collectors.

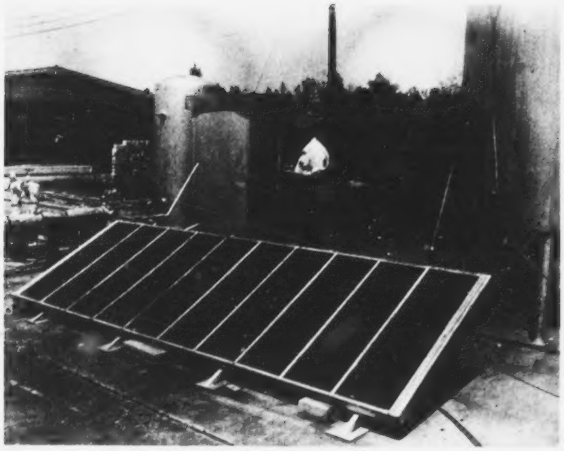


Figure 6. Florida-type solar water heater.

Figure 7. Solar water heaters in an apartment house.

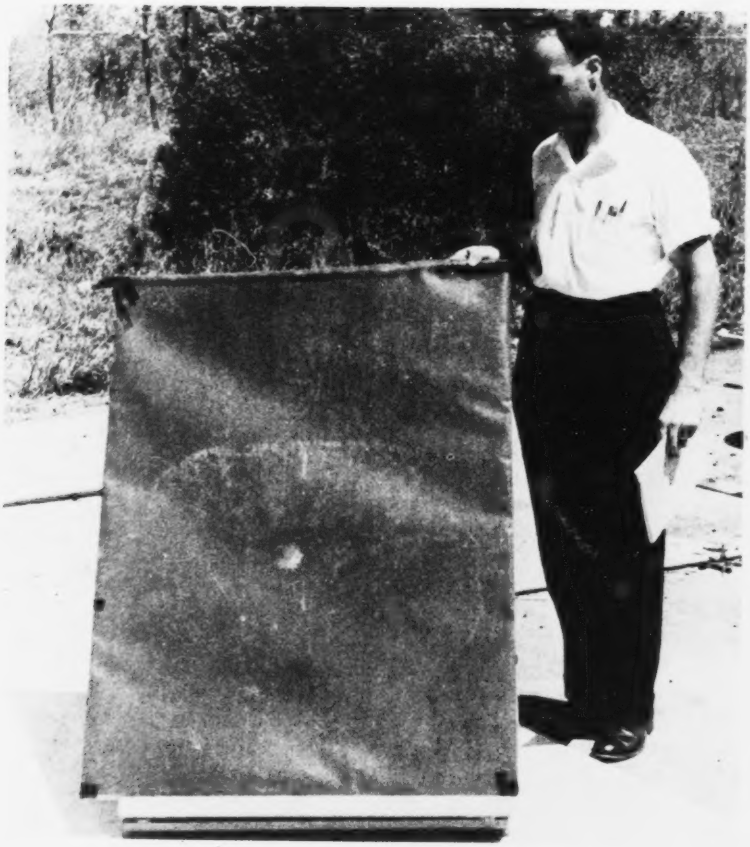


Figure 8. Swimming pool solar heater.

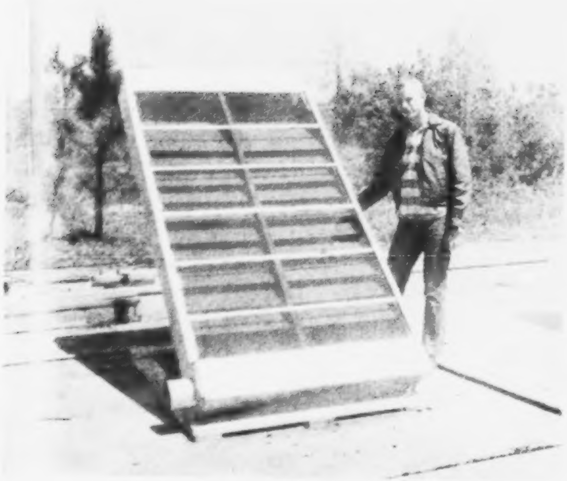


Figure 9. Solar air heater.

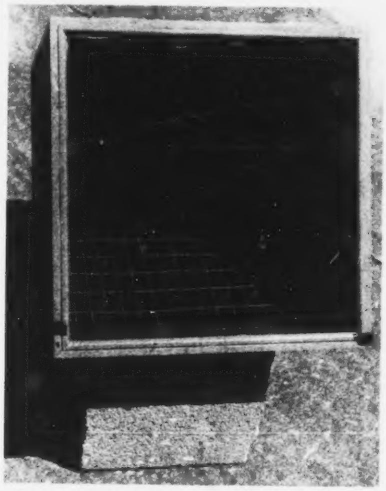


Figure 10. Solar oven.

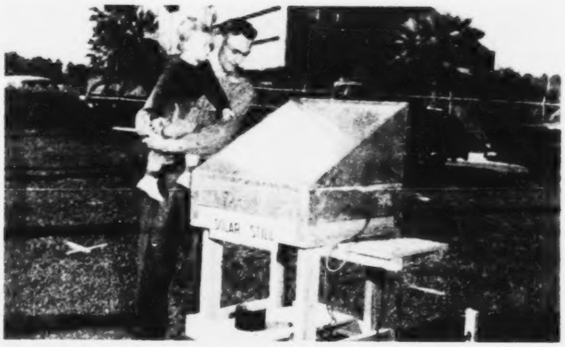


Figure 11. Small solar still.

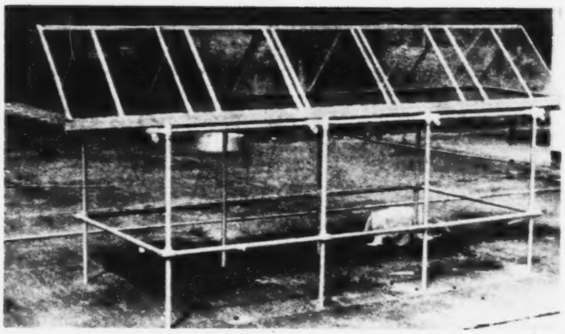


Figure 12. Larger solar still, also able to collect rainwater.

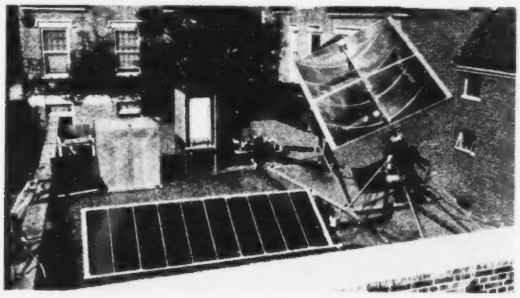


Figure 13. Refrigerator driven by solar energy.

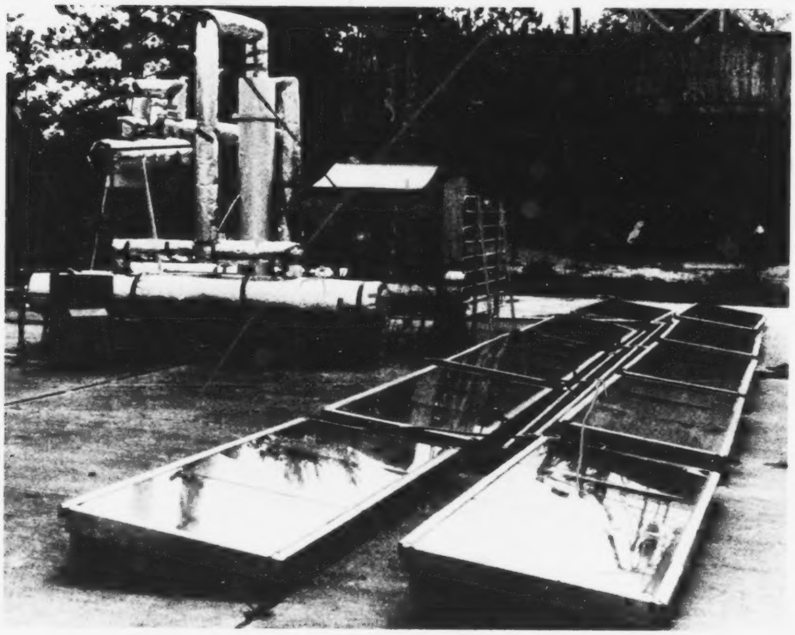


Figure 14. Five-ton solar air-conditioning system.

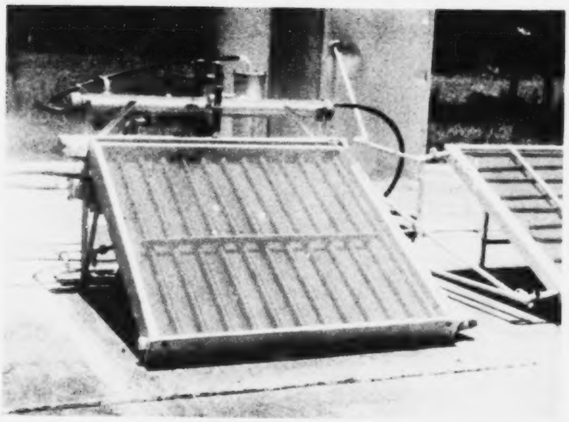


Figure 15. Small solar refrigeration system, front.

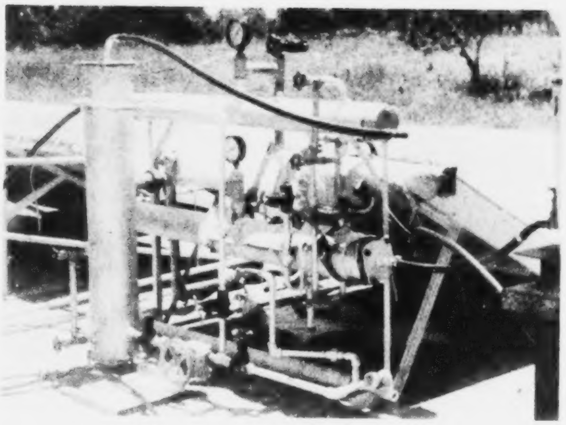


Figure 16. Small solar refrigeration system, back.

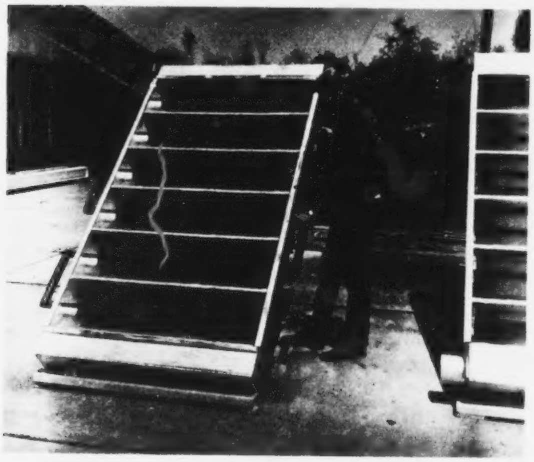


Figure 17. Stationary high-temperature absorber.

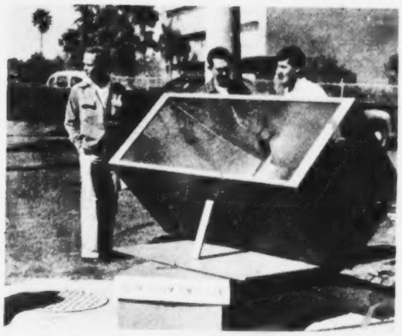


Figure 18. Solar steam boiler of solar steam power plant.

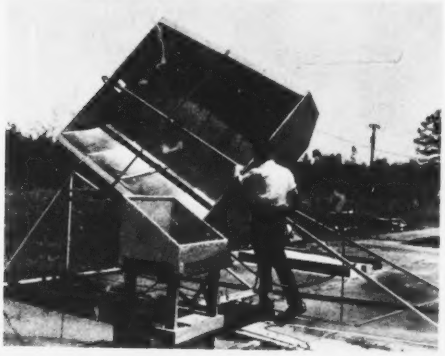


Figure 19. Cylindrical parabolic absorber, 6 by 8 ft.

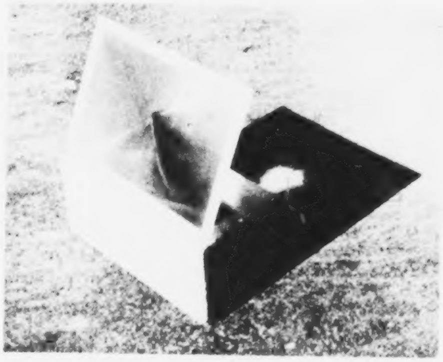


Figure 20. Plastic Fresnel lens.

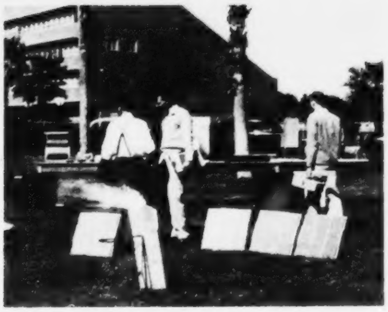


Figure 21. Solar concentrating panels.

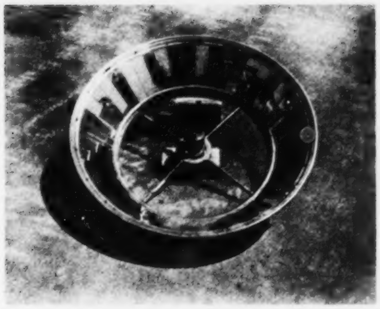


Figure 22. Solar cooker.

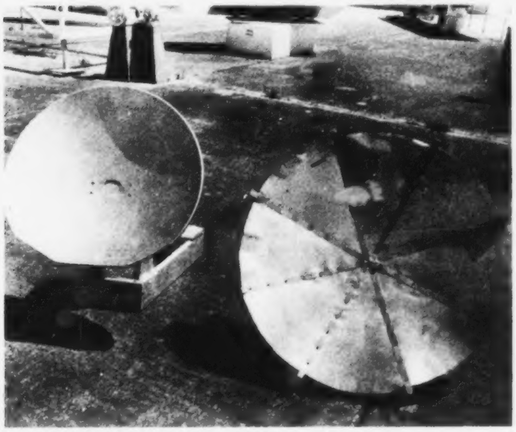


Figure 23. Parabolic solar concentrators.

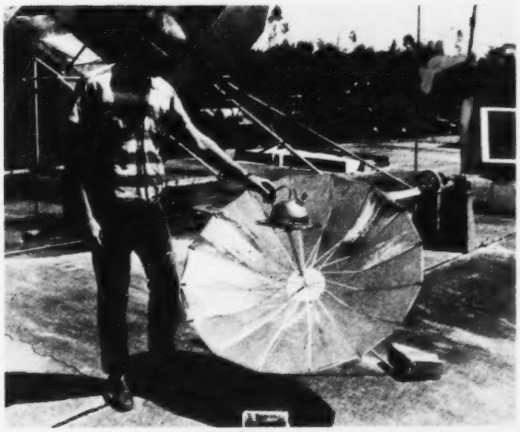


Figure 24. Collapsible solar cooker.

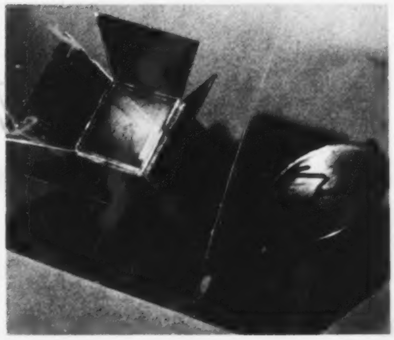


Figure 25. Solar oven and solar cooker.

Figure 26. Concentrating mirrors.

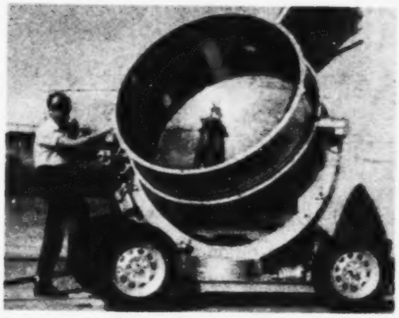


Figure 27. Five-foot solar furnace.

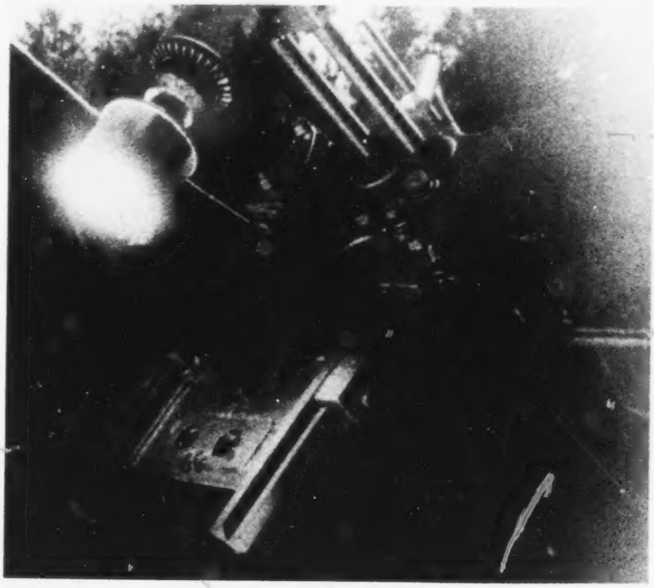


Figure 28. Concentrating solar energy.

Figure 29. High-temperature crystal growth from the solar furnace.

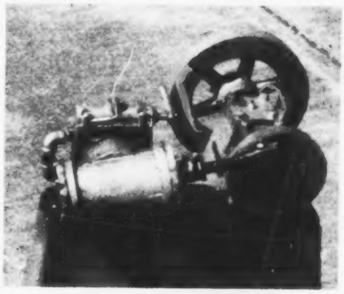


Figure 30. Small steam engine.

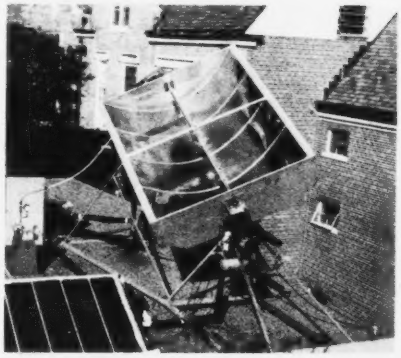


Figure 31. Steam engine operated by solar energy (one-fourth horsepower).

Figure 32. Solar steam power plant (see also Figure 17).

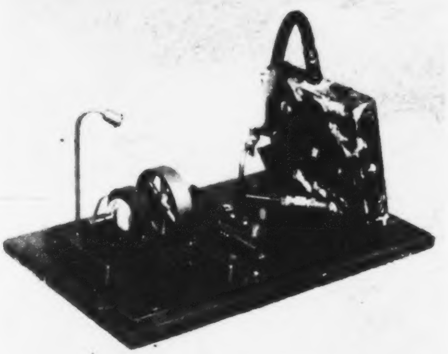


Figure 33. Solar steam power plant (see also Figure 21).

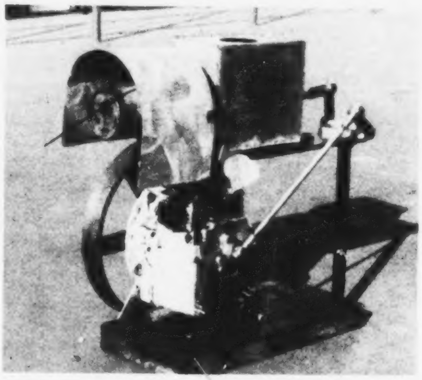


Figure 34. Closed-cycle, hot air engine – one-fourth horsepower.

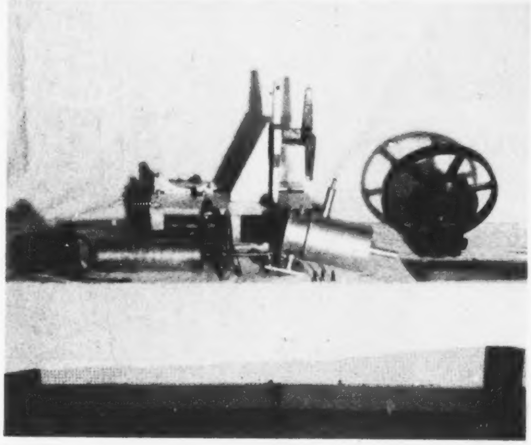


Figure 35. Disassembled, closed-cycle hot air engine.

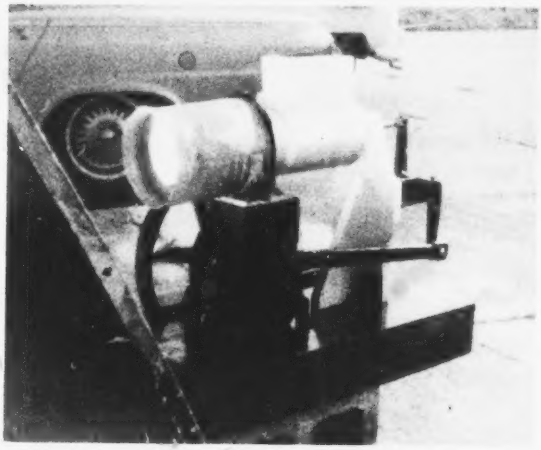


Figure 36. Hot air engine operated by solar energy.

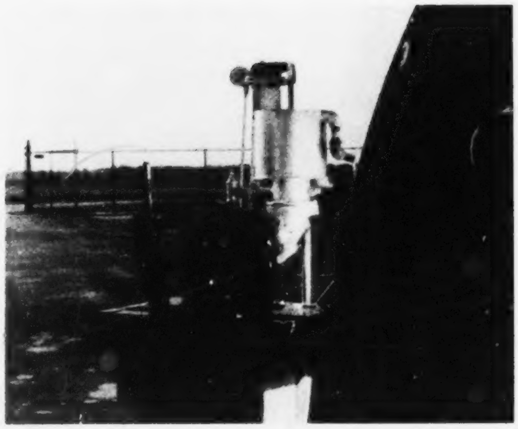


Figure 37. Closed-cycle, hot air engine.

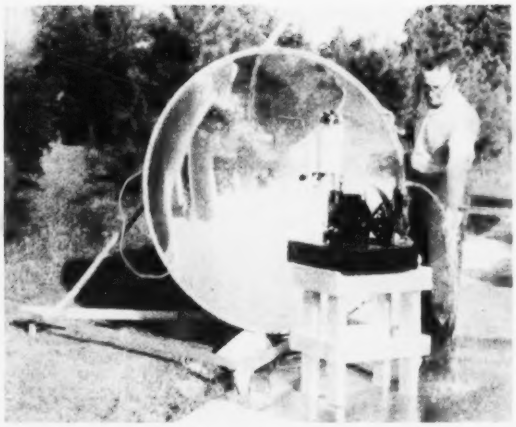


Figure 38. Pumping water with solar energy.

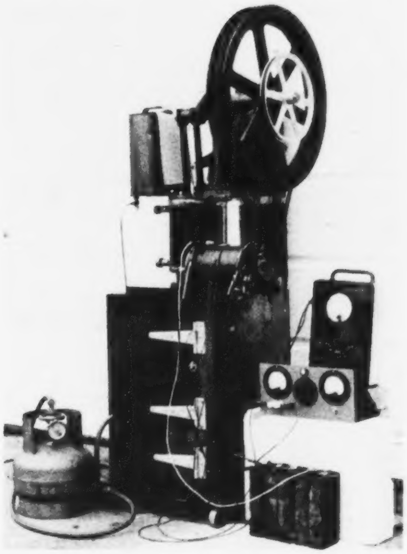


Figure 39. Closed-cycle, hot air engine.

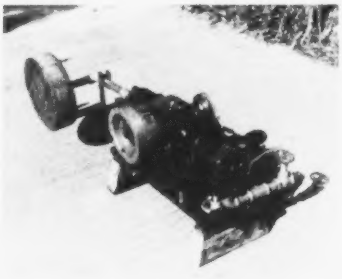


Figure 40. Open-cycle, hot air engine.

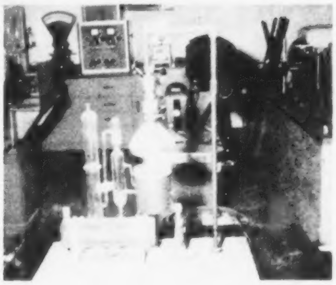


Figure 41. Solar pump.

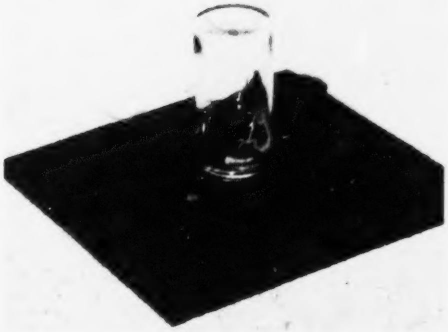


Figure 42. Solar turbine.

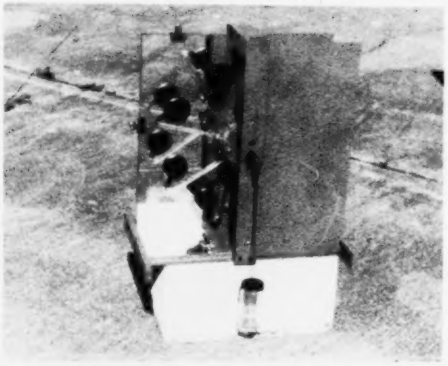


Figure 43. Solar gravity motor.

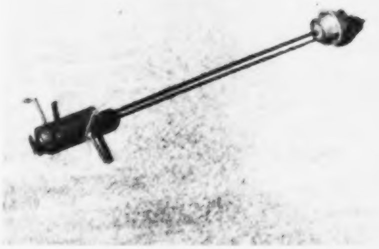


Figure 44. Solar thermo-phase shift reciprocating engine.

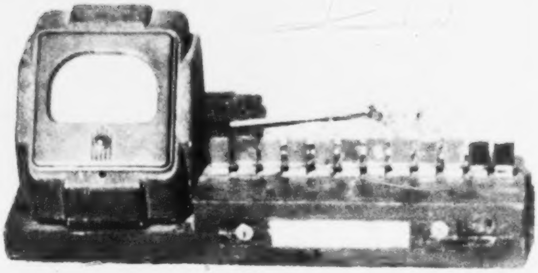


Figure 45. Solar cells.

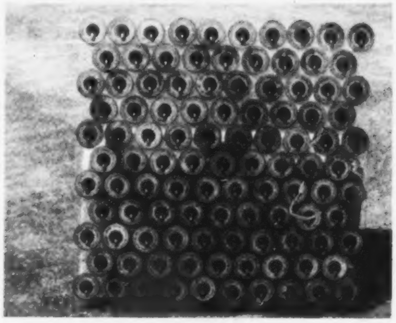


Figure 46. Solar cells.

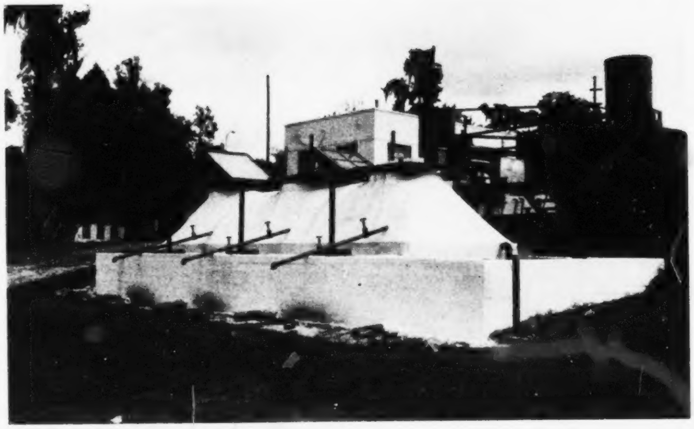
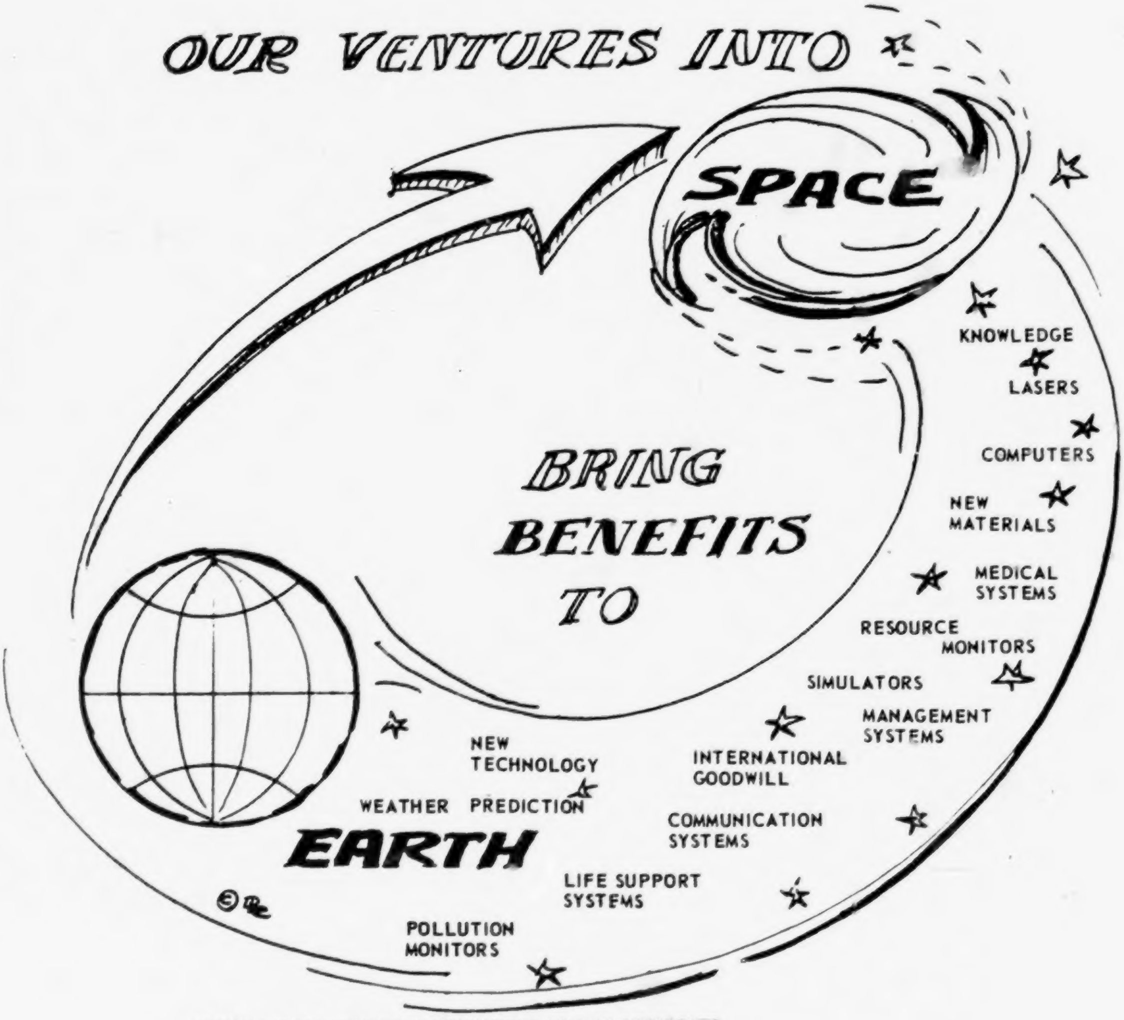


Figure 47. Sewage digesters.

# SESSION IX

# GENERAL TECHNOLOGY UTILIZATION IN THE PUBLIC SECTOR


OUR VENTURES INTO
SPACE
BRING
BENEFITS
TO
EARTH
KNOWLEDGE
LASERS
COMPUTERS
NEW MATERIALS
MEDICAL SYSTEMS
RESOURCE MONITORS
SIMULATORS
MANAGEMENT SYSTEMS
INTERNATIONAL GOODWILL
NEW TECHNOLOGY
WEATHER PREDICTION
COMMUNICATION SYSTEMS
LIFE SUPPORT SYSTEMS
POLLUTION MONITORS

SOME OF THE MANY "DOWN-TO-EARTH" BENEFITS RESULTING FROM SPACE RESEARCH AND EXPLORATION (CHART COURTESY OF D.L. CHRISTENSEN)

# APPLICATION OF SPACE BENEFITS TO EDUCATION

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NASA — Marshall Space Flight Center, Alabama

and

Frederick I. Ordway III
Professor, Science and Technology Applications
University of Alabama in Huntsville

The Alabama Section of the American Institute of Aeronautics and Astronautics (AIAA) established a study group to determine reasons for the decrease of public interest in space activities, and to propose remedial measures. Recommendations called for deeper involvement of the community to create broader public awareness of the many identified benefits from space. Other engineering societies were invited through the HATS to participate in a lecture series, the organization of a space benefits congress, and workshops to be conducted as a joint venture with the local educational system, which would benefit greatly from new space knowledge, and the application of advanced technologies.

This paper presents information on the conducting of a teacher workshop. This educational pilot project updated instruction material, used improved teaching techniques, and increased student motivation. The NASA/MSFC industrial facilities, and the displays at the Alabama Space and Rocket Center (ASRC) were key elements of the program, including a permanent exhibit, at the latter, on selected benefits accruing from the space program.

The summer workshop was structured around anticipated broadcasts from forthcoming Apollo Lunar and Skylab Space Station missions. Engineers, teachers, and scientists are now defining requirements that these broadcasts will impose on teachers and the school systems of cities, counties, and states. The Skylab mission may show that educational broadcasts should be made a major element of future manned space missions, especially with proper support by well-coordinated classroom activities. To assure maximum benefits to education from these Skylab activities, sourcebook-type data will have to be prepared and distributed to teachers and students. The value of technology, the systems approach, and the need for adaptability of any future system to changes were emphasized throughout the workshop.

Because of the positive response of teachers and students, follow-on workshops for educators from Huntsville and elsewhere are being considered. The workshop project will enable teachers to improve classroom education for life in the space age, recognizing that an understanding by youth of space-derived science and technology is a prerequisite for maximum progress in mankind's drive to improve life here on earth.

## Introduction and Background Information

Public interest in the nation's space program has decreased greatly in spite of several successful lunar landings. The events of the Apollo XIII and XV missions revived this interest somewhat, but this does not appear to be a permanent improvement. This lack of support has become of great concern to the aerospace community. Accordingly, the Board of Directors of the AIAA's Alabama Section initiated a study of underlying causes and suitable measures to remedy this situation. This study concluded that this new knowledge is often only visible to a handful of scientists, although such information can aid in the solution of many of the problems facing the nation today. Unfortunately, it is widely dispersed, existing in many governmental departments, in associated industries, and in universities and nonprofit organizations.

These facts have created a situation where space-oriented scientific and technological efforts have been criticized to be the least understood of ongoing national endeavors; the man-in-the-street does not understand the importance of space research to his standard of living, and he does not know of the advances already made. The benefits of space exploration have never been properly explained to the public, which is generally not aware of the fact that the space program has led to greatly improved global communications, including worldwide color television programming of major events and 3-day weather forecasts of good accuracy. The impact of the latter, alone, on sports events and recreational activities cannot be measured in simple dollars and cents, nor can a monetary value be placed on timely hurricane warnings that have saved many human lives.

Forthcoming contributions from the Earth Resources Satellites will be even more amazing. These flights will begin in 1972, and continue through this decade. Zero gravity will permit testing of previously unexplored natural phenomena and will improve our understanding of physics, chemistry, biology, and biotechnology. The greatest contributions have been or will be made to the application of advanced technology and program management to our multitude of worldly problems and their technology-oriented solutions.

To obtain active participation by other sectors of society, it was proposed to combine the efforts of the AIAA with those of nonaerospace-oriented organizations. Accordingly, HATS was approached for cooperation in such an undertaking. HATS consists of various professional and engineering organizations, most of which, on the national level, are not tied to the space program, although most Huntsville chapters do actively support space activities. HATS agreed to support efforts to make the public aware of the myriad of benefits from space, and a joint undertaking was started in late 1970 to organize and manage the various tasks involved.

## Public Lectures on "Benefits from Space"

AIAA and HATS members determined that it was important to furnish credible answers to the following types of questions:

1. What are the future goals of the space program?

2. How do these goals compare with those of the Apollo program?

3. Why should the nation continue the space program in spite of the many pressing problems in other fields?

4. How have space technologies aided nonspace industries and endeavors?

5. What direct benefits have resulted, and predictably, will result from the space program?

It was recognized that these questions could best be answered first, through a series of lectures, presentations and discussions, and later, through teacher workshops. These requirements led to a series of lectures on "Benefits from Space" shown in Table 1. Ten subjects were presented to an audience of up to 100 persons per evening, gathered in the ASRC in Huntsville, Alabama. Since scientists and engineers were the speakers, the audience was normally rather sophisticated, usually about half the attendees were associated with aerospace activities. The remainder was made up of specially invited science teachers of public high schools, as well as senior high school and university students. Attendance by the general public was rather limited, but increased as the series progressed. Suitable and effective publicity appeared to be a major problem. A permanent result of these activities is a new exhibit at the ASRC on space benefits, which was dedicated at the beginning of the 1971 summer season.

Selected subjects have been furnished to the NASA Space Mobile organization and have been worked into presentations by its lecturers. They have been adapted to all school levels, but have particularly been oriented to the younger grades and their teachers.

Studies made following the initial lecture series have shown that a most important audience appears to be gathered in our schools, where we find a representative cross section of the general public. Education in the U.S. involves a sizable portion (25 percent - 30 percent) of the population. Our youth is greatly interested in and often highly informed about space flight. Their teachers, on the other hand, are often reluctant to discuss the space program, its challenges, and results in great part, because they do not have relevant and easily understood material for teaching purposes. Suitable assistance from the aerospace community will enable the school system to teach about the new space knowledge, in general, and space benefits and dividends, in particular.

Education can probably benefit more and faster than any other profession, from space know-how and the application of advanced technologies. Concentrating on the teachers will optimize use of available resources, and also make good use of the "multiplier-effect," once the teachers start to apply the new knowledge in their classrooms. A few years hence, today's pupils and students will make up the majority of the general public. Through the teachers, the entire future population can be reached at impressionable ages and made aware of space program goals, technologies, and benefits.

## Summer Teacher Seminar

To implement the conclusion of an Ad Hoc Committee for a teacher workshop program, HATS announced that a teacher seminar would take place in late summer, 1971, on the subject "Educational Benefits from Space." The 1-week seminar, held in Huntsville, Alabama, was oriented toward benefits from space. It discussed the uses and applications of the new information, gained during the first decade of space exploration. Also, plans for and expected results from future space flights were on the agenda. The seminar was enhanced by visits to appropriate MSFC laboratories, local industries, and the ASRC. The University of Alabama in Huntsville (UAH) assumed the responsibility for the actual conduct of the seminar under MSFC and ASRC support. Topics presented at the seminar, including speakers or lecturers, are listed in Table 2.

The seminar addressed broadcasts from NASA's remaining Apollo missions and the Skylab mission, presently scheduled to fly in the spring of 1973. The scientific objectives of the Skylab experiments and their expected benefits were discussed. Included were experiments on solar and stellar astronomy; earth surveys; biomedicine and biology; and space physics and chemistry, with demonstrations of the effects of zero gravity on all natural phenomena. This kind of space research appears to provide an ideal framework to discuss the benefits from space achievable from future NASA flight missions. It was expected that this type of seminar, as well as potential follow-on seminars given elsewhere, would adequately prepare our educational system to obtain maximum benefits from the space program.

## Seminar Extension by Teacher Workshop

Those teachers who were willing to spend an additional week for a greater in-depth study of the educational benefits from space were invited to participate in an exercise to use the workshop technique and the systems approach to prepare future classroom activities in support of forthcoming space flights. Additional visits to MSFC and other local facilities were a part of this extension, as well as discussions with associated engineers, scientists, and systems analysts and managers.

This workshop served a different intent than other aerospace workshops; it particularly responded to the findings of the previously described HATS efforts, which do not make other workshops obsolete but specify a precise role for them. This workshop highlighted means to apply the new space knowledge to our educational system. Expert engineers and scientists discussed the impact of the space age on mankind's future living conditions on earth, creating novel educational requirements. Teachers were provided with advanced scientific information, which has not yet been fed into the educational system. It is hoped that this speedup of the information flow to the teachers will also accelerate inputs from space into all our earthbound endeavors. In turn, early missions are expected to assure maximum benefits to everyone involved. Such a situation will generate an alert, informed and highly responsive public.

Accordingly, the scope and the aims of this particular pilot workshop (and, hopefully, regular follow-on workshops) were as follows:

1. Important results of recent space events as well as goals of forthcoming space research were discussed with the highly motivated participants of this workshop, who will funnel this knowledge to the final user, the general public. Thus, everyone will quickly benefit from this information which can be applied to the solution of the many problems facing the nation today. This accelerated flow of educational knowledge will assure that space-based technology is properly considered in plans to solve the many local, national, and global problems. Such solutions are now being planned, managed, and implemented by persons who are not intimately aware of the tremendous potential that new management techniques,

new technologies, improved information systems, mass memories, and rapid computation methods will have on all future activites. It was the purpose of this workshop to complement the many individual and direct contacts between specific space efforts and associated scientists or experts by broadly based educational activities in many new fields. This first workshop was considered a pilot project for enlarged activities of similar nature, in the future, to bring the benefits from space to everyone.

2. This workshop stressed the answer to the question, "Why are we doing these things?" Other workshops have addressed the question, "What is being done?," describing hardware, programs and projects, systems (such as propulsion, guidance, control, air bearings), and similar subjects. These workshops should continue to lay a sound foundation in these fields. This new benefits-oriented workshop described the advantages that other nonaerospace-oriented fields of endeavor could reap from this new human capability to do things from outer space, unhampered by earth's gravity field. Our energy source, the sun, can be observed with visibility, unfiltered by the atmosphere. For the first time in man's history we also now have the capability to obtain a really vast overview of events down here on our globe, coupled with a tremendously improved communications system. These new capabilities will have an impact on the future life on earth, greater than anything that has happened heretofore. It is the task of our educational system to prepare our pupils for these years. A joint NASA/university/industry/education effort will be required to accomplish this goal, and only a first step in this direction has been taken.

3. The intent of this workshop was to prepare teachers for forthcoming space missions, such as two more Apollo flights, an extended Skylab program, future Space Shuttle flights and Space Station operations, and eventually, a large-scale earth orbital system of activities. It also made the teachers and the educational system aware of needs for new equipment, new educational material, and a well-trained and prepared teacher corps capable of meeting the new requirements. This need for enhanced education for the space age will be there, regardless of the role the U.S. is eventually going to play in the application of space capabilities and/or the exploration of the universe. Life on earth will be greatly affected, in any event.

4. This workshop was also to initiate a two-way channel of communications between the needs and desires of our educational system and the potential of space exploitation. NASA and industry scientists learned firsthand about the problems in teaching; the educators were made to understand the capabilities and constraints of space flights. It is hoped that a working-group relationship can be established and maintained for maximum mutual benefit.

It was also expected that particularly relevant and meaningful suggestions from the workshop participants would be considered for broadcasting from Skylab, particularly if no equipment changes are required — only modifications of the "scenario" and some Skylab operations. In any event, hardware modifications are practically impossible because of the advanced development status of the Skylab. A much more basic definition of educational broadcasts from space stations and experiment modules is possible and will be pursued. The University of Alabama in Huntsville is coordinating an effort with this goal in mind.

5. This workshop was also used to demonstrate the usefulness and applicability of a little-understood byproduct of the space program: a greatly enhanced system management capability. The workshop was organized in conformance with a sound system approach, which was applied by the teachers to their analysis and implementation of a series of television tapes produced to demonstrate the benefits from space. This firsthand experience underlined the value of systems management, and encouraged the teachers to apply system engineering to classroom education, overcome existing hurdles, and restructure educational methods and procedures. Moreover, a greatly increased necessity for continuing (adult) education would have to emphasize the new space-generated requirements. It was believed that only a thorough, system-oriented study and properly devised total system management would provide an acceptable answer as to how these requirements should be fulfilled.

6. The workshop also defined associated supporting activities needed in the schools. The new technological inputs have to be analyzed for their effect on classroom activities and the need for amplified teacher training. Additional teaching materia would have to be prepared in the form of a space benefits sourcebook. The maner in which this new information is presented would require that new types of equipment be obtained and installed, and operators for its use and repair would, of course, have to be trained.

## The Sourcebook

One of the most important tasks to be accomplished in the program to apply space benefits to education is the systematic accumulation and organization of space benefits information for teachers and students. This information would appear in the form of a sourcebook that would be used to enhance educational programs tied to actual space broadcasts, to provide a channel through which space-generated science and technology could be assimilated by teacher and student alike, and to supply a single fountain of data on the application of space knowledge to all fields of endeavor. Extensive sourcebook-type material is already available for review, discussion, and use. Indeed, the workshop used some of it, while at the same time, working up recommendations for follow-on improvements that would lead to a full-scale sourcebook on space benefits, supported by literature citations, teaching materials (e.g., charts, slides, filmstrips, films, and filmloops), and the like.

## Future Activities

Parallel to the actual conduct of the seminar and workshop, responses from city, county, private, and state educational institutions were obtained. Initial responses were favorable and indicated the readiness to amplify education on space in city, county, and state instruction, in the form of selective courses. A recent questionnaire sent to Alabama schools by the state education system indicated great interest to implement aerospace instruction as an elective subject. It is believed that this same situation exists throughout the country. To make such instruction as meaningful as possible, we must continue to generate up-to-date and interesting information for use by the teachers.

In support of this situation, the AIAA Alabama Section and HATS were asked to take the lead in the establishment of a Space Education Advisory Council, to advise the Board of Education in the definition of courses for aerospace education, to organize assistance from UAH, NASA, private industry, ASRC, state and city government, and possibly, other institutions. Full support has been assured by UAH as well as the granting of teacher credits and an interest in establishing a regular workshop program in support of aerospace education.

Besides these purely educational activities, it should also be tried to optimize information management as related to the U.S. educational system. University personnel cooperated with NASA and private industry to determine the impact of educational requirements on information management systems of future Space Stations and Space Shuttle flights. The presently foreseen Space Station will orbit in a flightpath which is ideal for education broadcasts, since it can address a majority of the people on the globe. It appears that a minor investment in educational information systems will enhance worldwide education tremendously. Drastic advances in educational technology seem to be required to make broad progress in continuing adult education economically feasible. Early Skylab broadcasts and geosynchronous educational satellites were considered as a pilot project for future space-oriented education, which would require supporting ground efforts prior to, during, and after the space broadcast. A pilot effort to study such possibilities in regard to future earth orbital systems activities is presently being researched by UAH and will be proposed to MSFC shortly. It can be shown that educational broadcasts from geosynchronous space can aid in the quick, efficient, and effective distribution of any information. Manned participation will be required in the conduct of many sophisticated space experiments, but will initially be limited to low earth orbits. A lecture room can be set up in these low earth orbits to demonstrate the physical, chemical, and biological behavior of various materials, living things, plants, and even the human operations. These same broadcasts can also explain the immediate benefits of earth surveys and earth resources management, as well as the long-range benefits of better understanding and improvement in our basic knowledge, which we can obtain from solar and stellar research. Once we have managed to arrange for such a far-reaching educational program from space, we have made a giant step toward the actual application of space benefits to all our daily activities.

## TABLE 1. SPACE BENEFITS LECTURES AND SPEAKERS

| | | | |
|---|---|---|---|
| 1. | Benefits from Space Stations | Dr. K. Ehricke<br>R. Holmen | North American Rockwell Corp.<br>McDonnell Douglas Astronautics Co. |
| 2. | Skylab Experiments and Objectives | C. De Sanctis | Marshall Space Flight Center |
| 3. | Dividends from Space | Prof. F. Ordway | University of Alabama, Huntsville |
| 4. | The Systems Approach - A Space Lesson | J. Aberg and others | Marshall Space Flight Center |
| 5. | Results from Lunar Exploration | G. Heller | Marshall Space Flight Center |
| 6. | Sound, Noise, and SST | I. Vatz | Teledyne - Brown Engineering |
| 7. | Nuclear Energy for Power | R. W. Hunt<br>Dr. J. B. F. Champlin | Westinghouse Electric |
| 8. | Weather Satellites and Meteorology | W. Vaughan and others | Marshall Space Flight Center |
| 9. | Space Exploration for World Peace | Dr. Mercieca | Alabama A&M University |
| 10. | Why to Explore Space? | Dr. Stuhlinger | Marshall Space Flight Center |

## TABLE 2. LISTING OF SEMINAR TOPICS AND SPEAKERS

| | | |
|---|---|---|
| 1. | Registration - Introduction | C. Hammett |
| 2. | NASA's Educational Program | E. Collins |
| 3. | Dividends from Space Technology - An Overview | D. Christensen |
| 4. | The Systems Approach - A Space Lesson | J. Aberg |
| 5. | Skylab Mission and Concept | L. Belew |
| 6. | Skylab Experiments and Objectives | C. De Sanctis |
| 7. | Earth Surveys | Dr. McDonough |
| 8. | Weather Satellites and Meteorology | O. E. Smith |
| 9. | Space Manufacturing | H. Wuenscher |
| 10. | Application of Space Remote Sensing to Solution of Ecological Problems | A. Adelman |
| 11. | Results from Lunar Exploration | B. Jones |
| 12. | Information Management | Dr. R. Vachon |
| 13. | The Space Shuttle | T. O'Connell |
| 14. | The Lunar Roving Vehicle | S. Morea |
| 15. | Space Exploration for World Peace | K. Dannenberg |
| 16. | Why to Explore Space? | Dr. E. Stuhlinger |

# FROM SPACE — OUR HOUSING HOPES?

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## Introduction

It is obvious that if we are to build the new cities and new towns in cities (Fig. 1) urban planners are discussing, some pretty advanced construction techniques and materials are required. The real question, however, is: What will it take to build these towns and cities? This is not an easy question to answer, but let us attempt to examine certain aspects of the associated problems.

Although at this hour, unsympathetic voices to continued space efforts resound loudly over the land, it is easily shown that space developments have provided us with the know-how, the technology, and the approaches for dealing with many of our earth-based problems. This presentation deals with only one of these problems — Housing.

In these very brief moments, we shall give an overview of three points:

1. Material Advances
2. New Building Methods
3. Systematic Design and Building Management.

These three items will be treated from the viewpoint of the Design-Structures-Materials Complex, indicated by Figure 2 [1].

## Material Advances

First, a brief word about materials. It is clear that there are many aspects to the proper selection and effective utilization of materials for a successful structural design, particularly one for severe environmental conditions. As Figure 2 illustrates, there are strong interactions among materials, structures, and design. Furthermore, because of these strong interactions, it is most important that the rational design of the system be approached on an integrated basis, considering simultaneously the structure, materials, and design conditions.

However, the ability to accept the world's available materials requires an inventive approach to the challenging demands of design. Dreaming about removing limitations of materials, however, provides powerful incentives for research. Ultimately, we may envision a heterogeneous solid (a mixed material system, perhaps) possessing the desired variable mechanical and physical properties which will simultaneously satisfy all of the design functions. Giving vent to our imagination, we contrive the ultimate structure (Fig. 3), a structure resulting from an interplay of the highest order.

New exotic materials emanating from space technology, such as titanium, beryllium, carbon, boron, and special glasses, offer many design possibilities. On a higher order, we have several new material mixtures, called composites, which are strong yet lightweight and able to withstand severe load, temperature, and corrosive conditions. These too are developments necessitated to meet requirements of high-speed aircraft and space vehicles. Composites, in fact, are seen now to approach dream materials with tailor-made properties.

In general, composite materials [2] are divided into five basic groups (Fig. 4) by form of the structural constituents which determine the internal character of the composites. Since the structural constituent is generally embedded in a continuous matrix of another material, the matrix is called the body constituent. The matrix generally encases the structural constituent, holds it in place, seals it from mechanical damage, protects it from environmental deterioriation, and gives the composite form. Concrete, for example, is one of our oldest and simplest composites.

In particular, recent trends in the structural use of plastics (more precisely, reinforced plastic composites) have demonstrated the great potentialities of structural plastics in building. In addition to lending themselves to an infinite variety of shapes (Fig. 5), structural plastics can be employed in strong, tough, lightweight, and even light-transmitting structures. Although certain of these developments can be expected to have practical solutions of building problems, a number of difficulties still remain.

## New Building Methods

The urgent need to provide low-cost mass housing for the nation has posed a real challenge for the building industry. In particular, this need includes a variety of housing types; e.g., single-family detached units, low-rise, high-rise multiple units, etc. Let us examine a few of the proposed systems which show promise in meeting some of these needs.

Single-Detailed Units, Double Units. The following are some interesting designs for singular dwellings. These illustrative designs, selected for their uniqueness, are only representative of a variety suggested for the single-system housing market. During the past 3 years, a number of experimental designs have found their way into the literature.

Flexible-corridor dwelling. The Sam Davis system [3] is constructed of fiberglass and polyurethane sandwich panels, molded in C-shaped elements. The element is used as part of the floor, wall, and ceiling; four or more are bolted together to form an enclosure or room. In production, two molds are used: one for the outside skin and one for the inside skin. The space between the two skins is filled with a low density polyurethane foam. For other shapes, the "C" is cut at the factory to make either interior or exterior corners. Doors and windows are cut into the rooms on the site (Fig. 6).

Each room is connected to the others by flexible corridors, permitting many design variations, as suggested by Figure 7. Horizontally, electric services run through the units' subfloors and the corridors, the latter carrying also all mechanical systems.

Floating house. An amphibious structure [3], designed by Domenico Mortellito, is formed in two molds — one for the top, the other for the bottom — the two sections are bolted together (Fig. 8). Constructed of rigid urethane, such a structure could be molded, extruded, and cast by processes incorporating structural, insulation, acoustical and lighting factors. Rigid urethane is a flotation material impervious to the elements and thereby particularly suitable for such a structure; the design is by no means limited to the amphibious application. Figure 9 shows the bottom half of the house (at the top).

MASC extrusion process. A revolutionary new construction technique for continuously extruding buildings was developed by Midwest Applied Science Corporation (MASC) of West Lafayette, Indiana. The new MASC extrusion process makes it possible to "spin" buildings out in one piece (walls, roof, partitions, etc.) (Figs. 10, 11), and not piece it together from components, on the site. Fast-rising and hardening plastic foams are used as construction materials. Fast-reacting liquid ingredients are pumped through the arm into a mixer and immediately transferred into a molding form at the end. As the arm moves along, a continuous layer of material is deposited.

Foaming equipment and supply tanks are mounted on a truck, and the system in its entirety can be moved to the construction site without need for auxiliary equipment. The process is applicable to structures of all types and sizes, including farm shelter, warehouses, factories, and low- and high-rise buildings. The traveling mold is designed so that construction is not restricted to any one geometry. Any shape of wall, whether straight or curbed, can be erected. Figure 12 shows how the process can be used to generate other shapes. An articulated arm could be used that could be shortened or lengthened, or whose center of rotation could be shifted. Still other shapes could be generated by moving a linear slip along a pair of inclined edge ribs.

Filament winding. In addition to the exploratory work on composite materials, aerospace research and development has contributed to a useful fabrication procedure for building. This is the wraparound technique, exemplified by the filament winding of rocket cases, pressure bottles, and other aerospace components.

By winding continuous strands of resin-coated glass filaments on a collapsible mandrel (Fig. 13), high-strength, lightweight structures are achieved whose strength properties are tailored to meet the imposed stresses by orienting the filaments in helical, longitudinal, or circumferential directions as needed. This technique has been tried experimentally to produce room-sized boxes with two thin layers or facings of filament-wound resin-coated glass fibers surrounding a core of lightweight plastic form.

An extension to wraparound consisting of a combination of fibrous sheets, gypsum board, and honeycomb has been proposed for industrialized housing production [3].

Architectural Research Laboratory (University of Michigan) system. The Architectural Research Laboratory (University of Michigan) [5] has proposed a complete building system which utilizes the filament-wound technique (composite concept) to produce onsite housing shells (Figs. 14, 15). The inner and outer skins, only 0.10 in. thick, are separated by a nonburning polyurethane core 6 to 9 in. thick, to form tubes up to 36 ft long, 20 ft wide, and 8 ft high. Various combinations of these can be assembled, including two-story units whose inner skins are wound separately, and after core application, are combined for outer windings.

Lift-shape process. The lift-shape process [6] is primarily a method of construction of thin-shell structures that permits elimination of conventional form work. A structural skeleton is developed so that it can be fabricated on a horizontal plane and then lifted and warped (Fig. 16) into final position (Fig. 17) for a spray covering of concrete (Fig. 18) or other material.

The shapes that are available through various patterns of bars are almost infinite, and the creative imagination of the designer would seem to be the only limit on shapes available (Fig. 19). As the armature is warped from its horizontal position and assumes a finished shape, the naturalness of structural form becomes apparent; and, as the sprayed-on covering is applied and the structure is brought to completion, the sculptural qualities are readily apparent (Fig. 20).

Self-erecting structures. Significant among the new construction methods is the self-erecting structure. Present developments, significant as they are, are but transitional steps toward the fully automatic self-erection of structures. Ideally, a self-erecting structure would be brought onsite in some compact form. Then, with the addition of an energy input, it would automatically develop into a predetermined, expanded, stable form. Figure 21 [7] illustrates a variety of structural shapes and space applications and their deployment techniques. The space program has exploited these structures in a way which may be very applicable to architecture.

Self-erecting structures of the pneumatic type (Fig. 22) can produce a large variety of shapes by tailoring the fabric, providing internal elements and external restraints. The simplest form of pneumatic structure is that of the inflated membrane. The inflated rib is under pressure inside the rib and unlike the air-supported membrane, it does not require a heavy foundation to withstand the large uplift forces at the support. The quilt provides continuous multiple membranes. The pillow construction consists of two membranes held apart the desired distance by internal ties. Intersecting ribs provide a two-way enclosure with membranes between the ribs. Of course, most pneumatic structures are inherently self-erecting in that only air need be injected to develop a stable expanded shape from a compacted form [4].

Environmentalists will find William Moseley's imaginative design [8] most satisfying. The house, swimming pool, patio and gardens are enclosed in a plastic umbrella (Fig. 23). A boom extending over the house supports the umbrella and contains all plumbing and wiring. Sections of the bubble are mounted on tracks, and can be opened or closed at pushbutton command. Inside the umbrella, air is filtered; climate is controlled. Entry is provided by a driveway passing through an air curtain.

Finally, the potentialities of a newly developed structural system may be gaged, to some extent, by its versatility in being able to satisfy expected future trends on a broad basis.

Multiple Units, Large-Scale Units. Several of the techniques just discussed have direct application to the construction of multistory structures and large-scale housing units. Since we shall deal with the subject, in part, in our discussion of construction on a vast scale, for the present, only two from among several techniques applicable for multistory construction are examined.

Pneumatic construction. A recent development of the University of Sydney, Australia [9], has resulted in the application of pneumatic construction to multistory buildings. The underlying principles of the proposed system are illustrated in Figures 24 and 25. According to Figure 24, a flexible tube, when subjected to a proportionate internal air pressure, becomes a stable compression member. Furthermore, it is possible to utilize the load-bearing capacity of this structural system, whether the load is applied externally to the free end or suspended internally in the form of floors.

A typical design of a 10-story office building based on pneumatic criteria is shown in Figure 21. In the design on the left, access to the building is gained by means of an airlock tunnel at ground floor level. At ground and basement level, substantial plant areas are required for air-conditioning and pressurization equipment. These areas are not pressurized. The variation on the right shows a rigid, self-supporting membrane which is erected to full height before the building is pressurized. Here an open, pressured column supports a load on a piston which is in itself supported by internal pressure.

Tentatively, a pressure range of 0 to 14 psi internal pressure above external atmospheric pressure has been adopted for the design of multistory pneumatic buildings [10].

Modular high-rise system. The system developed by National Homes for Operation Breakthrough [11] combines a precast concrete space frame with steel modular boxes. The structure is extruded round sections of concrete pipe with a post-tensioned X-frame every four floors. The precast central core of the cruciform-shaped building contains the stairs and elevators. A crane is used in this construction, which limits structures to 24 floors. After the precast elements are erected (Fig. 26), the boxes are lifted and slid in on top of each other. Four pairs of modular boxes can be stacked on each X-frame. A typical one-bedroom box is shown in the bottom right of Figure 26.

Several types of small modules are joined to form each 14 in. wide unit. It may be desired, for example, to have several bedrooms and a bath in one module, and a living room, kitchen/utility core, and bedroom in another. Furthermore, the modules can be placed side by side or can be stacked up.

New Communities, New Cities. In contemporary society, we no longer expect people to stay rooted for reasons of family loyalty, economic security, or emotional attachment. Families move. Jobs change. Populations shift. Each year one out of every five American householders moves, changing homes, as they change jobs, income levels, spouses, age groups, desires, and life styles. The constant tearing down, remodeling, and rebuilding that occurs in today's cities testify to the fact that continual change is needed and desired. New approaches which address themselves to these contemporary requirements of mobility and reversibility are the subject of the present discussion.

The concept of reversibility [12] is rather new to architectural design, and perhaps, a few preliminary remarks are in order. This is a form of architecture that can be dismantled nondestructively or collapsed in a reverse manner to that in which it was erected. As the life process of a city changes, the location of many structures would optimally change with it. A certain shop, for example, might be forced to abandon its location for particular reasons. If the building were designed for easy reversibility and shipment, it might not only be moved to another part of the city, but perhaps to another city or state.

Reversibility, however, is not intended to be restricted to small buildings, as is possible today. With technological developments, it should be possible to sectionally and systematically dismantle a structure of any size, including megastructures. An evolutionary trend toward hard, large-scale reversible structures can currently be noted, particularly in housing. The well-publicized Moshe Safdie's high-rise Habitat (Montreal, Canada), and the 21-story Palacio del Rio Hotel (San Antonio, Texas) are possible solutions to reversibility, although neither was originally intended to be reversed.

The Acron house (Fig. 27), designed by Carl Koch, in 1948, is an example of a prefabricated house that utilized initial deformability characteristics. Initially, the house is a movable package of approximately 180 square feet. The walls, floor, and roof fold around the central utility core — kitchen, heater, and bath. Closets are also stored here when the home is folded. When expanded the house contains 810 square feet.

More generally then, architectural form can be inherently deformable, expandable, displaceable, disposable, and to some extent, capable of kinetic movement [12]. To take full advantage of these characteristics, however, there must be established new criteria for materials, new technology, new construction techniques, new building economics, etc.

Reflecting some efforts in this direction, the following multifacility systems have been proposed for urban or regional populations:

Arcology. Paolo Soleri conceives future cities with more than a million people living in vast multilevel structures. Soleri's city-design concept, called Arcology, is an integration of architecture with ecology. It is a total planned environment, dwellings, factories, utilities, entertainment centers, within a single megastructure 1 to 2 miles wide and up to 300 stories high. Making maximum use of three-dimensional space, freeing nine-tenths of the surrounding land for farming and leisure, arcology combines the benefits of urban and rural life and provides alternatives to congestion, pollution and resource waste. Because the diameter of an arcology is small, walking, bicycling, escalator, elevator, moving sidewalk, and pneumatic or electric vehicle transport make automobiles unnecessary except for travel outside the arcology.

Two examples of such multilevel structures are: the three-dimensional Jersey and the Hexahedron (Fig. 28). The three-dimensional Jersey (top) is a 13-$\text{mi}^2$ transport center for a million people, planned for Jersey swamps. The main structure is circled by park-covered industrial buildings, farms, airstrip, etc. Two Hexahedrons (bottom) are each 3600 ft high, 3300 ft wide, and house 170 000 people. Pyramids textured surface permits architectural adaptation to individual tastes and needs.

Although the conceptions have been rejected by some as mere pipedreams, they do represent real challenges for the interplay between structure, material, design, and, of course, ecology.

Plug-in city. In architecture and urban planning, the concept of interchangeable components had been explored by two groups in particular, the Archigram Group (England) and the Metabolists (Japan). The objective is to create buildings which are so basic and adjustable that they can meet future changes. In the most general terms, the results are designs which are of indeterminate form, assembled from expendable components. Basically, the buildings are composed of two components: a basic skeleton or latticework or mast which acts as structural supports and carries mechanical services, and expendable modules or capsules which can be plugged-in, removed, or replaced.

The plug-in city (Fig. 29) [14], by the Archigram Group, is a complete urban complex that explores many aspects of the concept. Cranes remove, install, or service substitutive accommodation capsules. The giant latticework serves for both life support and structural support. Lateral expansion can take place along the lines between A and B. Plug-in city has been described as "a city of components on racks, components in stacks, components plugged into networks and grids, and a city of components being swung into place by cranes." Its success, however, may depend upon new lightweight, fireproof, and economical structural materials; equally important are new, quick, and cheap techniques of fabrication.

Super-roof structure. An instant plastic building has been developed by the Ferro Corporation. The process employs flexible plastic material that hardens under sunlight in hours or in days, depending on the sizes of the structure and the temperature. Once cured, the material is claimed to be relatively indestructible. The material may be possible to build structures up to 0.5 mile in diameter. The ultimate size will be established after complete stress analysis of full-size structures. Made of woven fiberglass impregnated with tough cylindrical plastics, the structures are translucent, permitting 80 to 90 percent light transmission. They are dome shaped or cylindrical in outline. The light weight of the finished shell makes these structures easy to transport. A structure 50 ft in diameter should weigh about 2500 lb.

In the future, immense super-roofs utilizing this concept could cover entire cities. Such megastructures are depicted in Figure 30 [15].

Sea city. The technology to build floating cities already exists. One proposal for such a floating city is the recent Triton City [15] designed by Buckminster Fuller. The city would be created in three stages. The first stage, or module, is a neighborhood of from 3500 to 6500 people. It can be composed of a string of four to six small platforms accommodating about 1000 people each or of a larger 4 acre triangular platform which could house 6500 people. Each neighborhood unit would contain a small supermarket, an elementary school, and local stores and services. The second module (second stage), a town, is created by linking together three to six neighborhoods, which would create a population of 15 000 to 30 000 people. For this combination, a town platform is added containing a high school; more commercial, recreational and civic facilities; and perhaps, some light industry. The third module, the last stage, is a full-scale city of 90 000 to 125 000 population. It is created by connecting three to seven towns and will include a city-center module containing governmental offices, medical facilities, etc. Units, of course, could be added or subtracted if the needs of the community should change, thus allowing and providing for incremental growth. The proposal is being considered for implementation by Baltimore, Maryland.

The city at sea (Fig. 31) [17], conceived by Pilkinton Glass Age Development Committee (London, England), is another proposal of the concept of floating cities. The designers envisage a glass-and-concrete offshore island for 30 000 inhabitants that could be comparable in cost to a conventional land city but would not use vital food-producing land. The site suggested for the first sea city is 15 miles off the east coast of England in shoals covered by 35 ft of water at high tide. Although such a project may not be realized for 50 years, the structural and engineering techniques needed exist today. Sea city could also be economically feasible and capable of providing all the facilities of a mainland town. The complex would be a 16-story amphitheater on piles, with a central lagoon warmed by waste heat from the city's industries and containing a cluster of floating islands that carry houses, schools, and public buildings. A breakwater of water-filled plastic bags would encircle the city as a first line of defense against waves, and a curved outer wall would deflect the wind. On-the-spot power from undersea natural gas would be the keystone of the city's economy and surplus fresh water from a desalination plant could be piped ashore to provide revenue. According to the designers, the kind of shoal water best suited for the construction actually exists over nearly 10 percent of the world's seabed, so there is no lack of suitable sites.

Undersea community. There is an ever-increasing possibility that undersea working and living may become a reality. Following Jacques-Yves Cousteau's underwater explorations and demonstrations of undersea living, several designs for undersea habitats are the subject of experimentation of several countries: U.S., Japan, United Kingdom, USSR, West Germany, etc.

One interesting design is a sea igloo, proposed by Edwin A. Link. Made of heavy-duty rubber, the igloo is actually an inflated house which works on the principle of maintaining equalized inside and outside pressures. When not in use, the igloo can be deflated, packaged and easily removed. An artist's concept of an underwater environment is shown in Figure 32 [18]. It is a "shirtsleeve environment" working and living facility, designed for depths up to, perhaps, 600 ft. A recent development of General Electric, an artificial gill, may free man from today's umbilical ties between undersea shelters and the surface and, eventually, from today's typical oxygen breathing apparatus used by divers. It is an ultrathin membrane of silicone rubber which admits air from the surrounding water and allows carbon dioxide from breathing to escape.

Space city. The ability to initiate efforts for actual living in space is largely based on the capabilities and experience obtained from over a decade of space exploration. The U.S. Skylab and Space Station programs and those of the USSR are clearing the way for mass utilization of space for habitation. Designs for space cities have already received serious consideration. Douglas Aircraft, for instance, has proposed a space ball complex which has a molecular structure that could be added to, much like a giant Tinker toy. Other proposals include enormous wheels and multispoked configurations in which the inhabitants circulate to other chambers via hollow spokes. The design (Fig. 33) is a space city complex with an average population of about 4000. The giant wheel consists of modules containing offices, laboratories, living quarters, and a hotel. A ferry system, perhaps similar to the proposed Space Shuttle of our own space program, would transport people and supplies from earth.

## Systematic Design and Building Management

Among the approaches to provide low-cost mass housing, it appears that the creation of an industrialized system of building, one that is fully automated, technologically advanced, well managed, and most important, free from artificial impediments, may be the best hope in the attack. In other words, it is felt that it would be achieved through an integrated approach. This suggests a systems approach to the problem.

The systems concept is a way of thinking and approaching problems, which involves looking at the entire problem rather than concentrating on one or more parts to the exclusion of everything else.

Systematic management, aerospace's most characteristic product, offers the broad-based, interdisciplinary approach so necessary to solve the extremely complex housing problem. The problem is not one of a purely technological nature but one requiring the proper adaptation of technology to the human interface in the city.

In closing, we will examine the general features of the systems approach as it may be applied to housing. First, however, a few definitions are in order to avoid the confusion resulting from the often indiscriminate use of the technical terms.

Systems building is a combination of parts in a whole. In systems building, the term building system is used for an entity comprised of subsystems that are fully coordinated and interrelated. Industrialized building is programmed and systemized building using a highly mechanized flow line. Prefabrication in building is the offsite fabrication of components or assemblies. Prefabrication is not prerequisite to industrialized building, even though it usually plays an important role in it. Figure 34 [19] illustrates the various elements of the building system.

Conceptual Model of the Housing System. There are five major elements in the conceptual model [20] of the housing system. First, there are people. The people exhibit many different characteristics, one of the most important of which, in terms of housing, is that to the owner or renter of a house. Second, there is the roof-finding system, which includes all institutions and individuals engaged in the process of finding and securing homes for people to live in. The third element is the collection of houses and residential land in the area. The fourth, and most important, is the match between the house and the renter and landlord or owner, called the house-occupant (H-O) pair. The fifth is the neighborhood or community, and a sixth is interest rates.

The model diagrammed in Figure 35 includes seven system elements. Two major processes are represented: the process involving people, or migration, and the process involving the housing inventory, or deterioration. In addition, two types of action are defined: those involving physical processes (double arrows) and those involving perceptual processes (single arrows). The forces acting on people are produced by physical processes, whereas the forces acting on the houses are the result of perceptual processes.

The change in people and the people themselves are represented in blocks 2 and 3, respectively. It is postulated that the H-O pairing (block 1), the neighborhood and community characteristics (block 1A and Table 1), and the external influences (block 4 and Table 2) are forces which, modified by the internal characteristics, act on the occupant to produce his behavior.

Consider now the blocks and loops. First, the double-arrow physical-process loop starting with block 2, which represents the occupant. There are two arrows out of this block, representing the decision outcome to stay or move. If the person stays, he then remains in the neighborhood matched to his house, as represented by the double arrows from box 2 to box 3 to box 1. His living in the house implies some physical effect on the house, both in terms of wear and tear and in terms of repairs or improvements. These physical processes are represented by the double arrow emanating from the house-occupant set (box 1) and entering the box representing change-in-house characteristics (box 5).

The second double arrow out of box 2 indicates the occupant's decision to move out of his house and neighborhood. In the event the person moves out of the neighborhood, the house to which he was matched leaves the neighborhood housing inventory (box 6) and becomes part of the roof-finding system inventory (box 7). Once matched, the new house-occupant pair reenters the neighborhood (goes from box 7 to box 1) [1A].

The single-arrow pair from box 1 to box 5 represents each of the physical processes (wearing out, repairs, maintenance) in turn. The loop from box 1 through boxes 5 and 6 back to 1 represents the deterioration process.

The Construction System. Buildings and the processes that create and put them into place are manmade systems with humanly defined objectives. A building, for example (like any other designed facility, for that matter), is a system, that is, an interconnected complex of functionally related components designed to accomplish a purpose [21].

Since the system is made up of components, they, in turn, constitute wholes with their own ordering of parts. The system then consists of several subsystems related one to another, each possessing the basic systems framework. Figure 36 [21] illustrates the construction process (the Construction subsystem), a subsystem of the building system.

Let us consider the structural model of the Construction process. The Construction process comprises three main steps: site preparation, component fabrication, and component connection. The process is affected by the Design process in the form of design specifications (materials, components, dimensions, and arrangements which together make up a building or facility). The design specifications, together with other inputs, enter the Construction process. The inputs are: land, labor, materials, capital, know-how, and design specifications. The objective is to achieve a building or facility with specified characteristics and subject to certain constraints. The constraints of the Construction subsystem are technological, institutional, economic, and climatic.

Some of the restrictions come from outside of the subsystem, others from inside. Feedback control within the model works in two ways. Should the performance criteria indicate discrepancies between inputs and objectives, changes in construction inputs are provided, and perhaps changes in the inputs of the design process are required.

## Conclusion

Obviously, in this brief overview, a number of aspects of our subject have, of necessity, been omitted. We did not, for example, discuss the various building systems themselves. Space limitations necessitated that such specific, but noteworthy information be sacrificed for a more general exposure.

In the foregoing, we have attempted to offer some developments of material systems and building methods that could be brought to bear on the complex housing problem. Some steps are already taking place. In addition, a suggested approach for dealing with the problem as it relates to other components within the total community or city structure has been mentioned. Most of these developments are traceable, directly or indirectly, to the space programs.

The degree to which these and other developments ultimately are utilized in the housing or building industry depends on the foresight, ingenuity, and progressiveness of the building industry itself. The potential for good design and for bringing good housing down into the price range where every American family can afford it and where we can make a serious start to rebuild our cities seems unlimited.

It is well, then, that we end on that optimistic note.

## References

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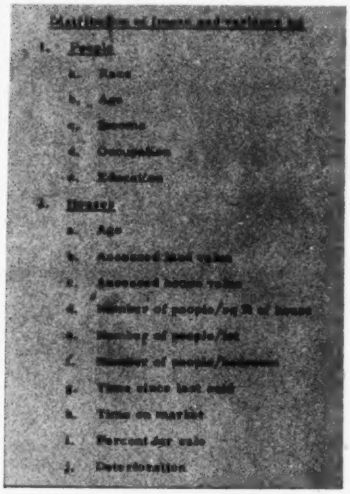
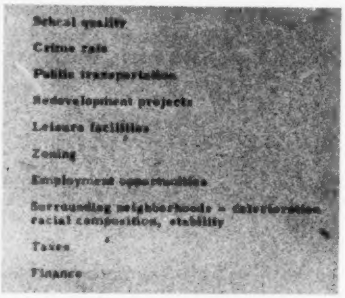
TABLE 1. NEIGHBORHOOD MODEL CHARACTERISTICS [21]



Distribution of [illegible]

1. People
   a. Race
   b. Age
   c. Income
   d. Occupation
   e. Education
2. Houses
   a. Age
   b. Assessed land value
   c. Assessed house value
   d. Number of people/sq ft of house
   e. Number of people/lot
   f. Number of people/bedroom
   g. Time since last sold
   h. Time on market
   i. Percent for sale
   j. Deterioration

TABLE 2. EXTERNAL INFLUENCES [21]



School quality

Crime rate

Public transportation

Redevelopment projects

Leisure facilities

Zoning

Employment opportunities

Surrounding neighborhoods - deterioration racial composition, stability

Taxes

Finance

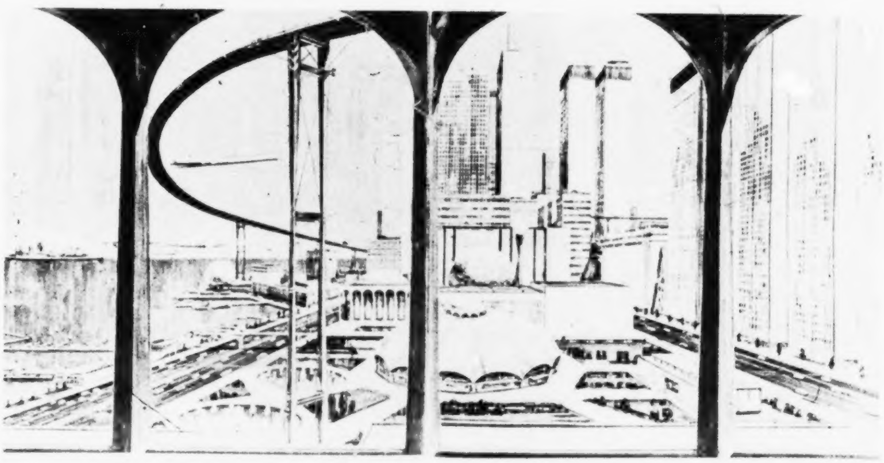


Figure 1. Our new city.

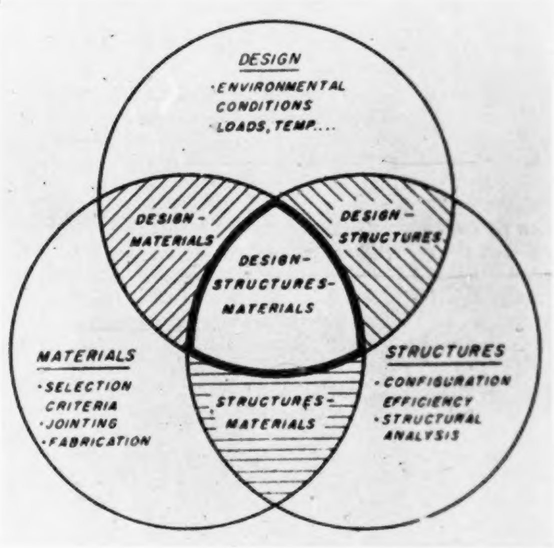

DESIGN
·ENVIRONMENTAL CONDITIONS
·LOADS, TEMP....
DESIGN-MATERIALS
DESIGN-STRUCTURES
DESIGN-STRUCTURES-MATERIALS
MATERIALS
·SELECTION CRITERIA
·JOINTING
·FABRICATION
STRUCTURES
·CONFIGURATION EFFICIENCY
·STRUCTURAL ANALYSIS
STRUCTURES-MATERIALS

Figure 2. Nature of the interplay (courtesy of Aero/Space Engineering).

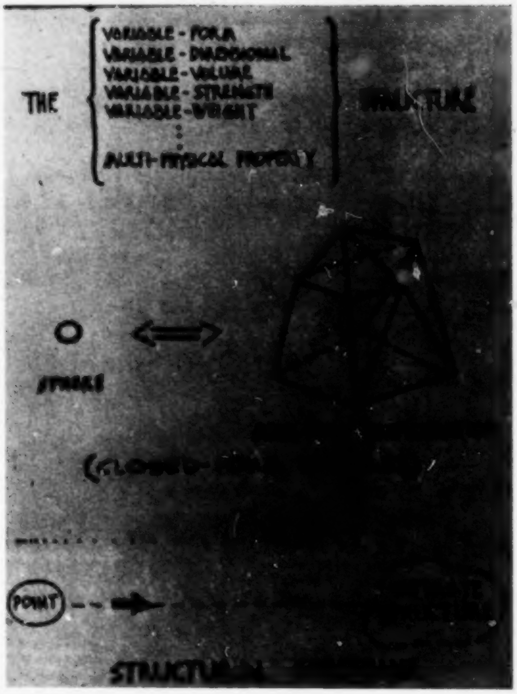

THE
VARIABLE - FORM
VARIABLE - DIMENSIONAL
VARIABLE - VOLUME
VARIABLE - STRENGTH
VARIABLE - WEIGHT
MULTI-PHYSICAL PROPERTY
STRUCTURE
POINT
STRUCTU

Figure 3. The ultimate structure.

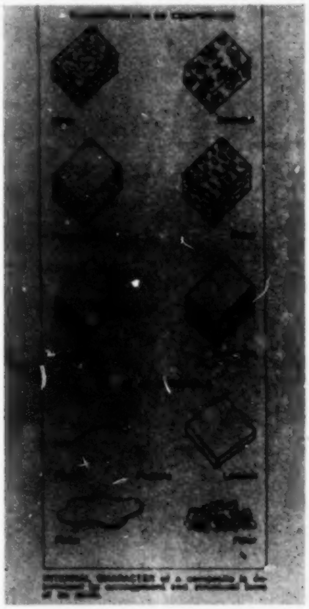


Figure 4. Composites.

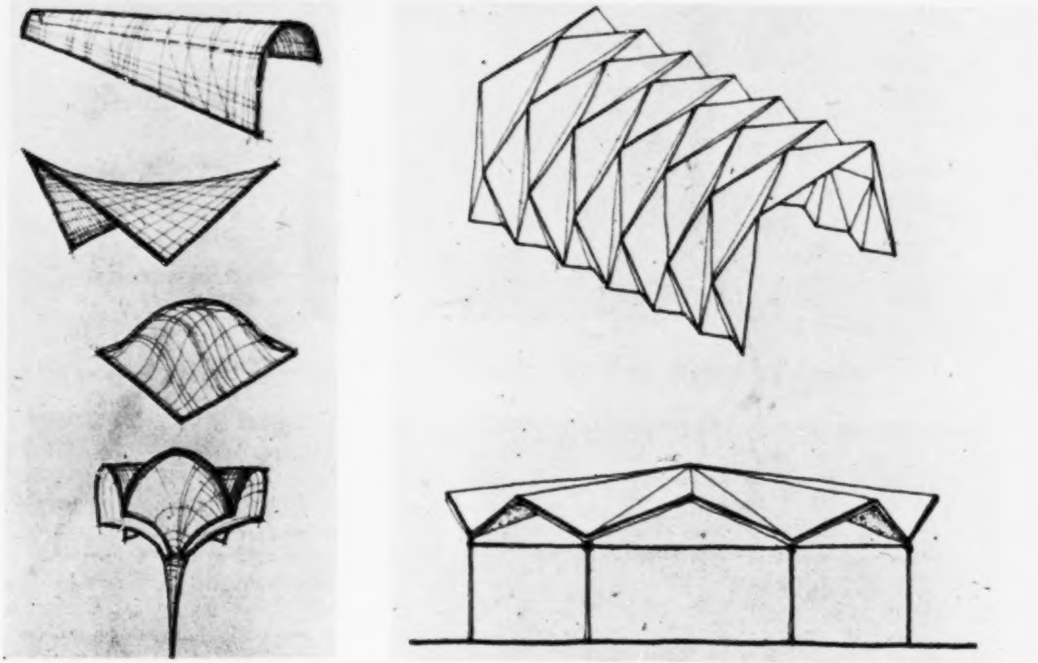
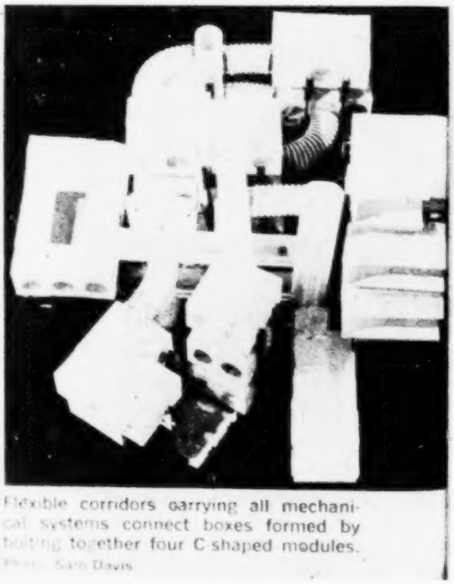


Figure 5. Some structural plastics shell forms (courtesy of Progressive Architecture).



Flexible corridors carrying all mechanical systems connect boxes formed by bolting together four C shaped modules.
Photo: Sam Davis

Figure 6. Flexible-corridor dwelling (courtesy of Progressive Architecture).

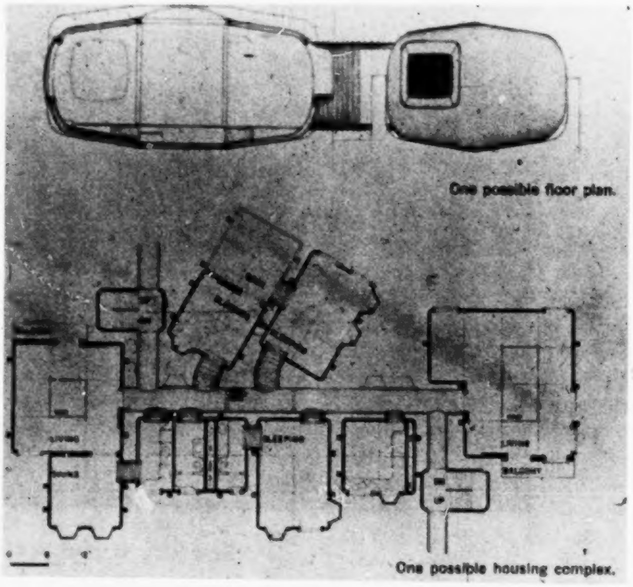

One possible floor plan.
LIVING
SLEEPING
LIVING
BALCONY
One possible housing complex.

Figure 7. One possible floor plan for flexible-corridor dwelling.

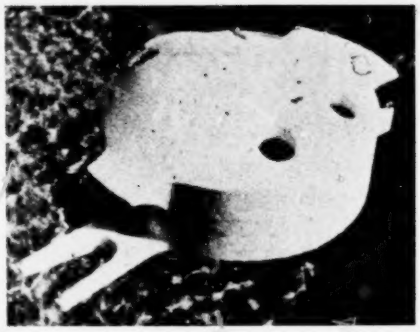


Figure 8. Floating house (courtesy of Progressive Architecture).

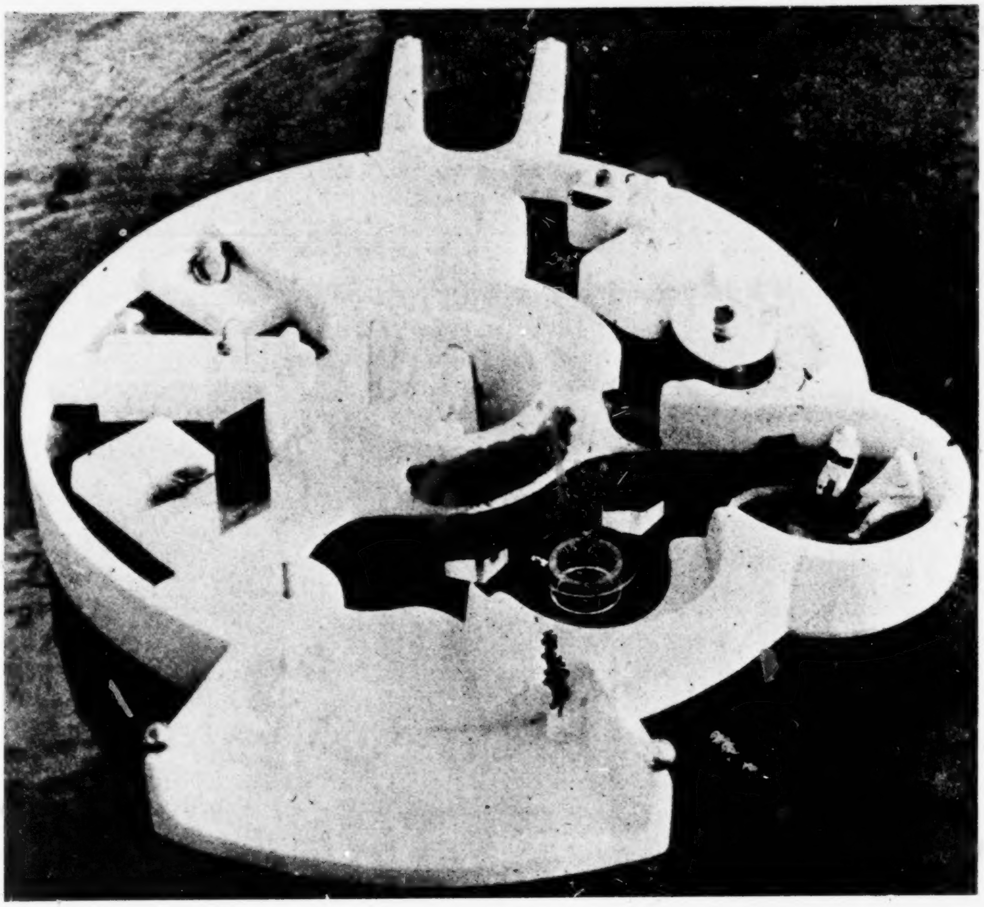


Figure 9. Bottom half of floating house.

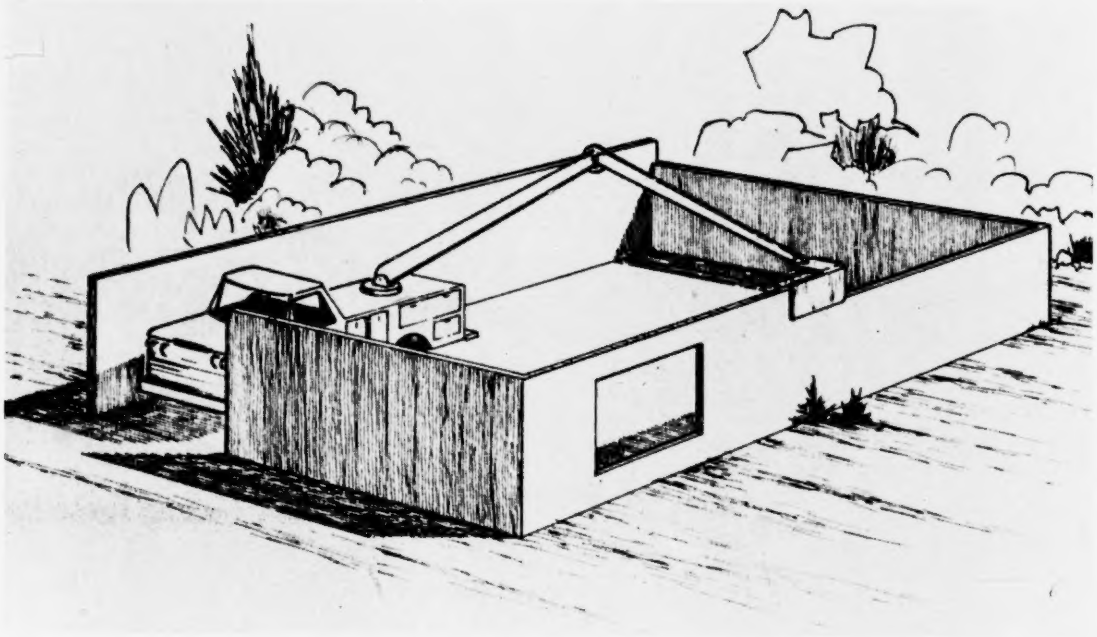


Figure 10. MASC extrusion process — wall formation of a rectangular building.

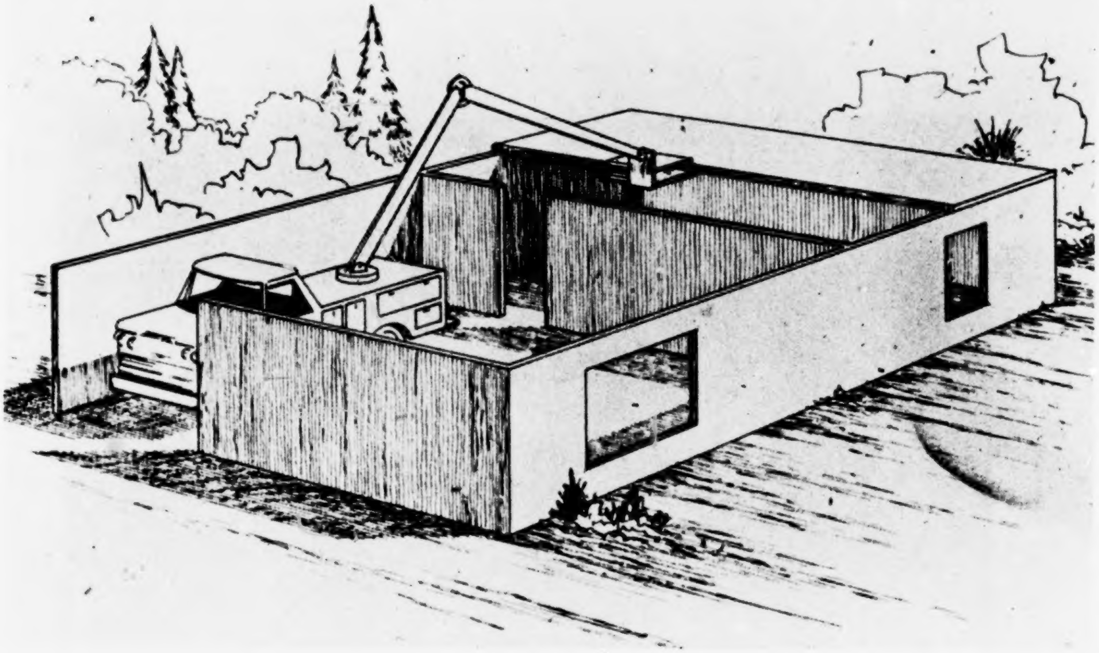


Figure 11. MASC extrusion process — ceiling and roof formation.

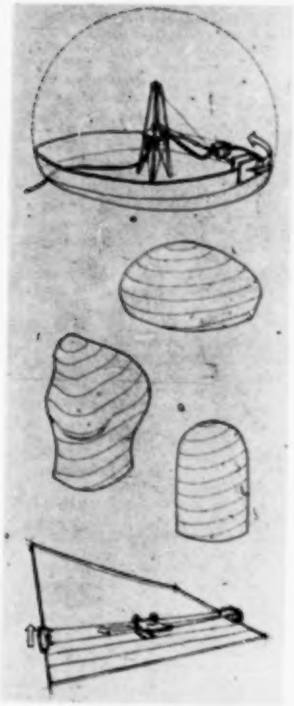
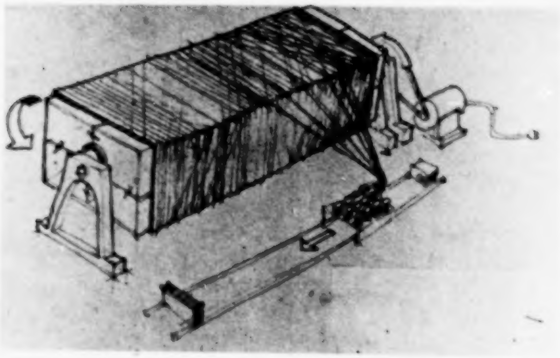


Figure 12. Some extrusion shell forms (courtesy of Progressive Architecture).



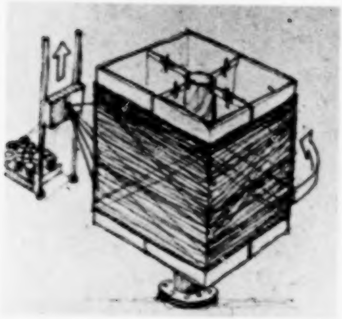


Figure 13. Filament winding (courtesy of Progressive Architecture).

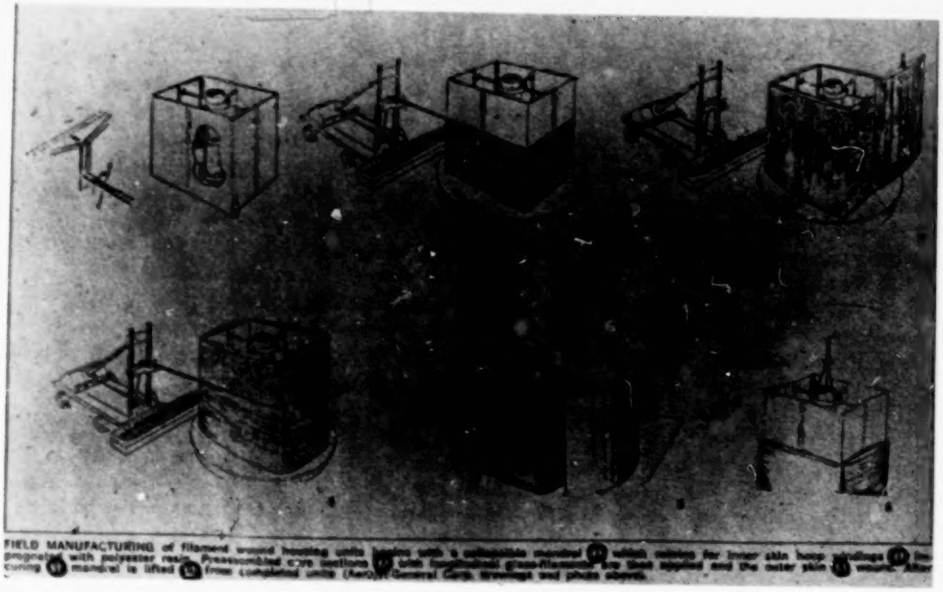

FIELD MANUFACTURING of filament wound housing units begins with a collapsible mandrel [illegible] which rotates for inner skin hoop windings [illegible] impregnated with polyester resin. Preassembled core sections [illegible] with longitudinal glass-filaments are then applied and the outer skin [illegible] wound. After curing [illegible] mandrel is lifted [illegible] from completed units [illegible] General Corp. drawings and photo above.

Figure 14. Architectural Research Laboratory (University of Michigan) system.

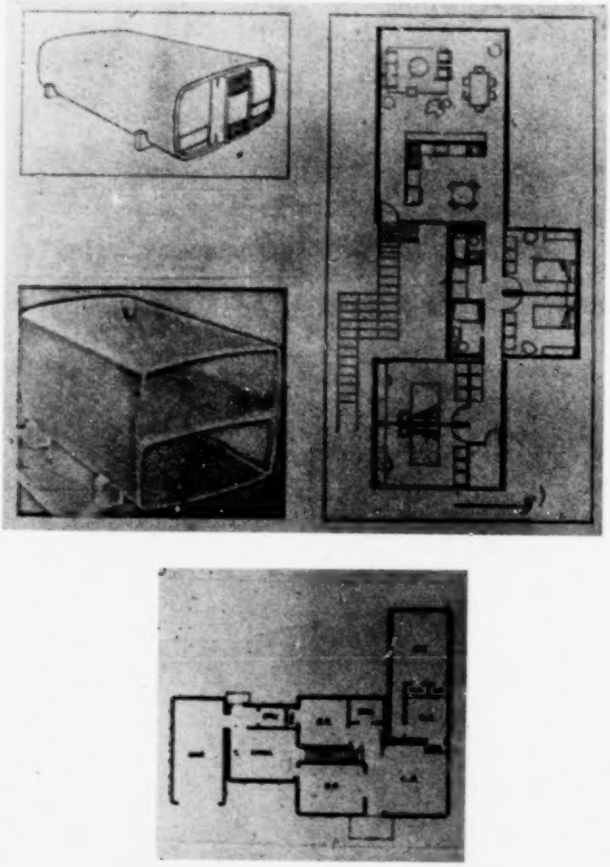


Figure 15. Completed units.

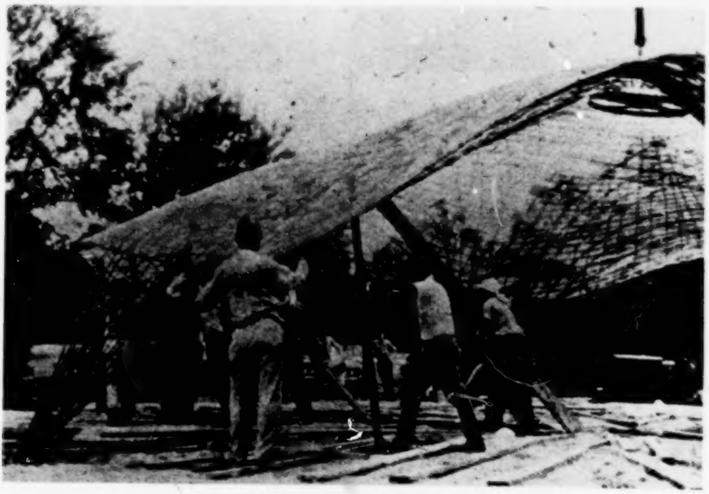


Figure 16. Lift-shape process [6] — placing temporary supports.

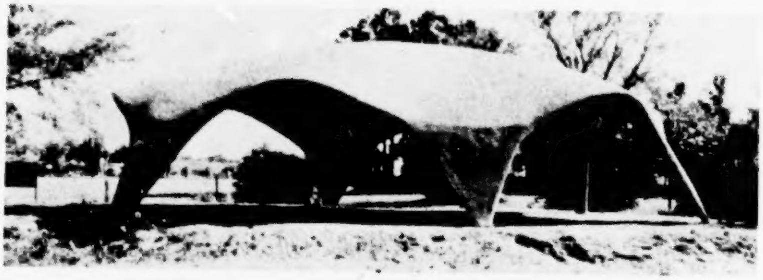


Figure 17. Final stage of construction [6] — completed steel armature.

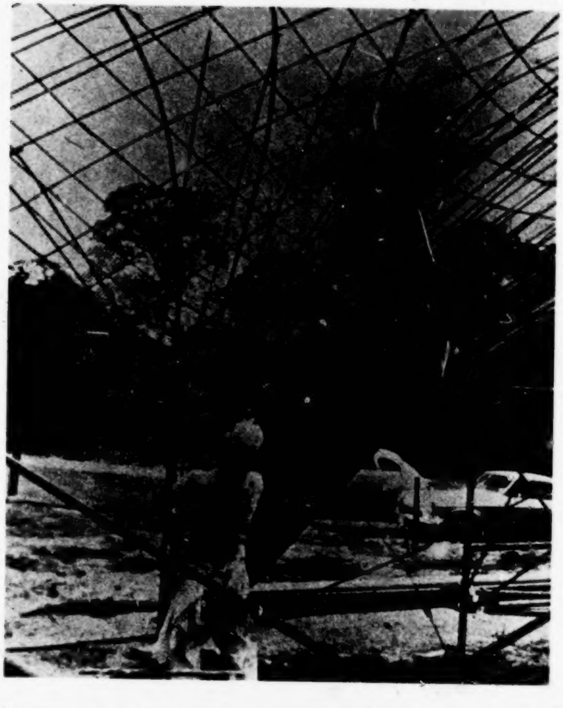


Figure 18. Final stage of construction [6] — spray application of first concrete coat.

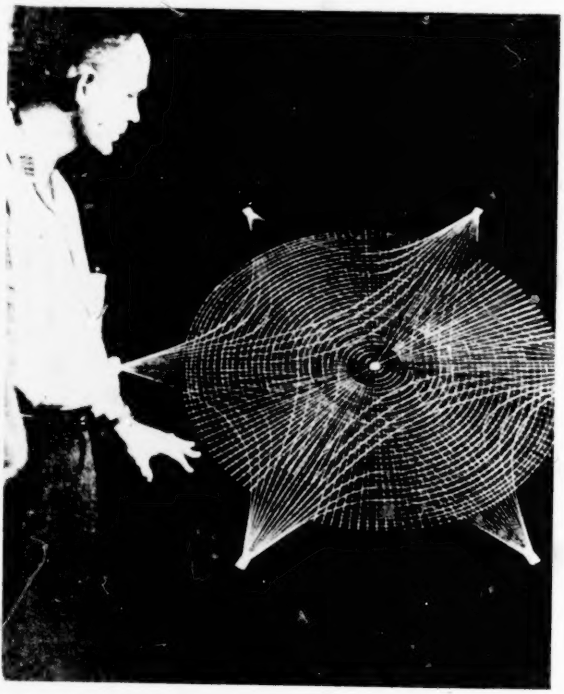


Figure 19. Bar pattern model of 50-ft span test structure.

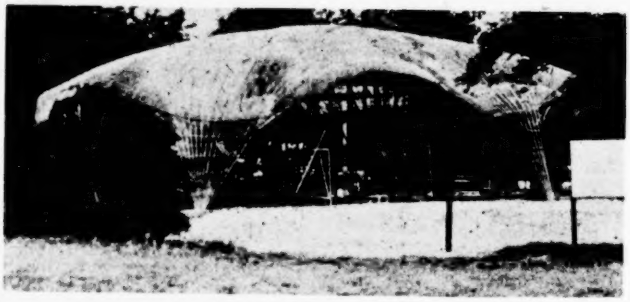


Figure 20. Final stage of construction — completed six-point parabolic shell.

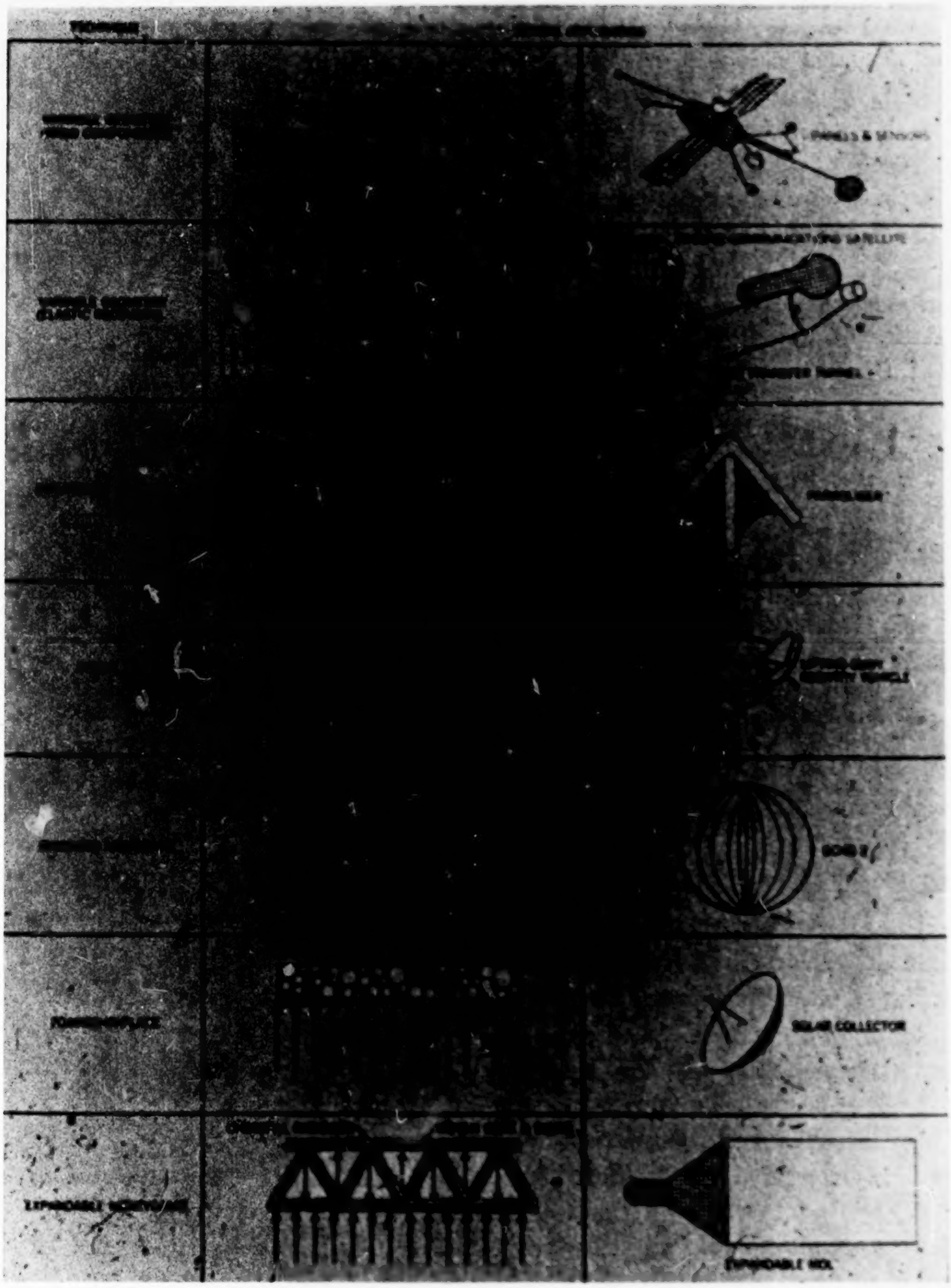

PANELS & SENSORS
TRANSFER TUNNEL
PARAGLIDER
ECHO II
FOAM-IN-PLACE
SOLAR COLLECTOR
EXPANDABLE HONEYCOMB
EXPANDABLE MOL

Figure 21. Expandable structures deployment technique and applications (courtesy of Space/Aeronautics).

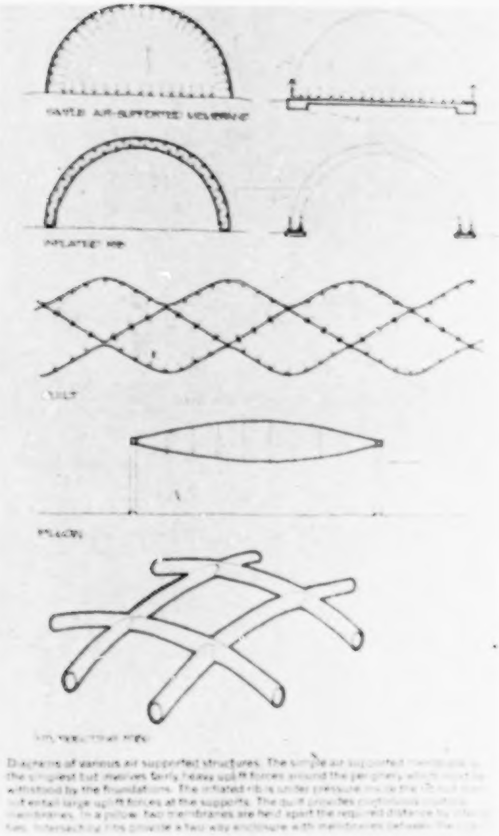


Figure 22. Diagrams of various air-supported structures (courtesy of Progressive Architecture).

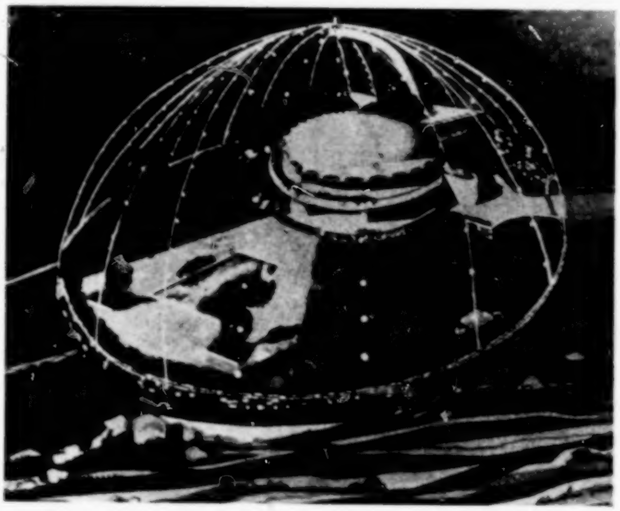


Figure 23. An oasis for living (courtesy of Machine Design).

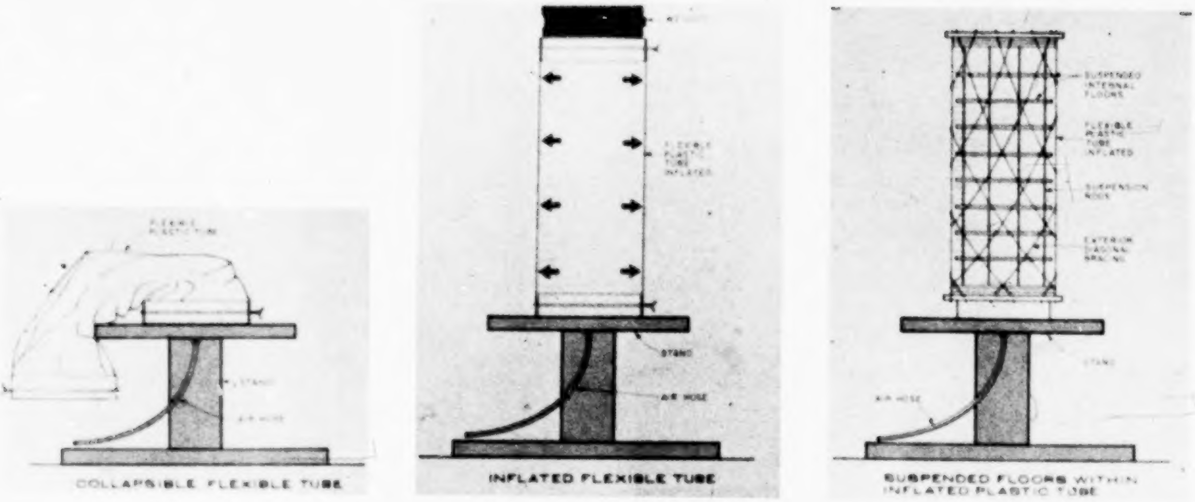

SUSPENDED INTERNAL FLOORS
FLEXIBLE PLASTIC TUBE INFLATED
SUSPENSION RODS
EXTERIOR DIAGONAL BRACING
STAND
AIR HOSE
COLLAPSIBLE FLEXIBLE TUBE
INFLATED FLEXIBLE TUBE
SUSPENDED FLOORS WITHIN INFLATED PLASTIC TUBE

Figure 24. Pneumatic construction applied to multistory buildings (courtesy of Progressive Architecture).

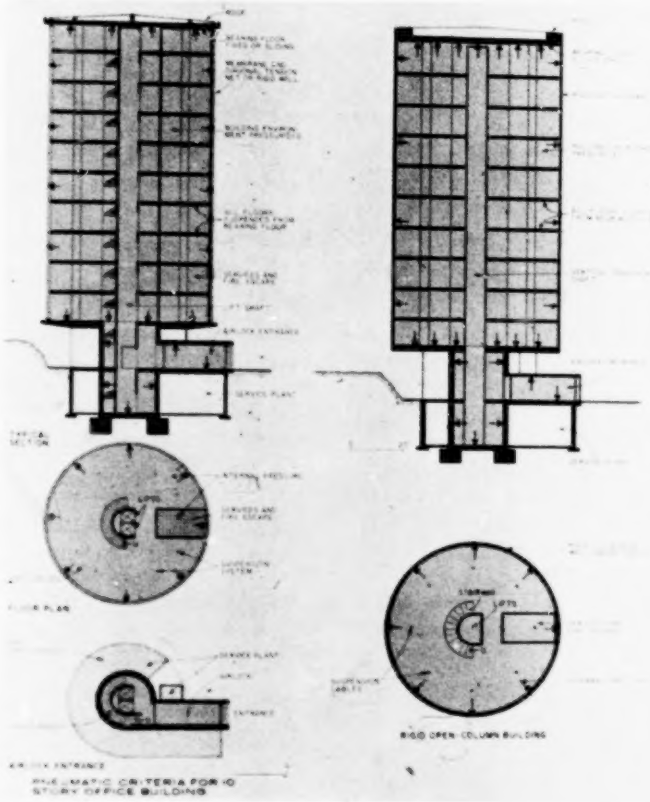

TYPICAL SECTION
FLOOR PLAN
AIR-LOCK ENTRANCE
PNEUMATIC CRITERIA FOR 10 STORY OFFICE BUILDING
RIGID OPEN-COLUMN BUILDING

Figure 25. Office building designs (courtesy of Progressive Architecture).

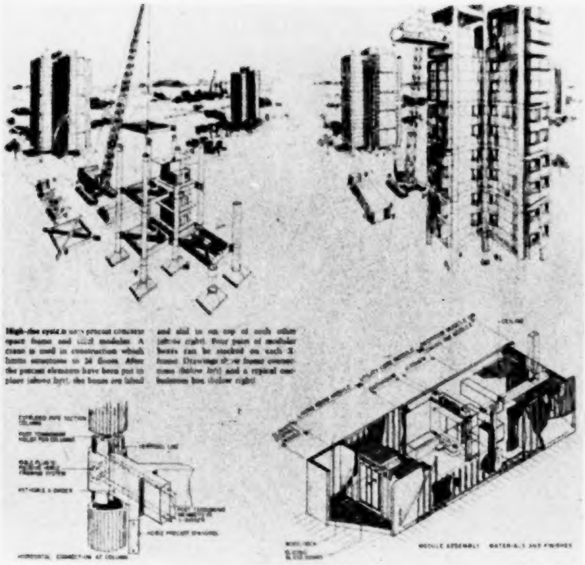


Figure 26. Modular high-rise system (courtesy of House and Home).

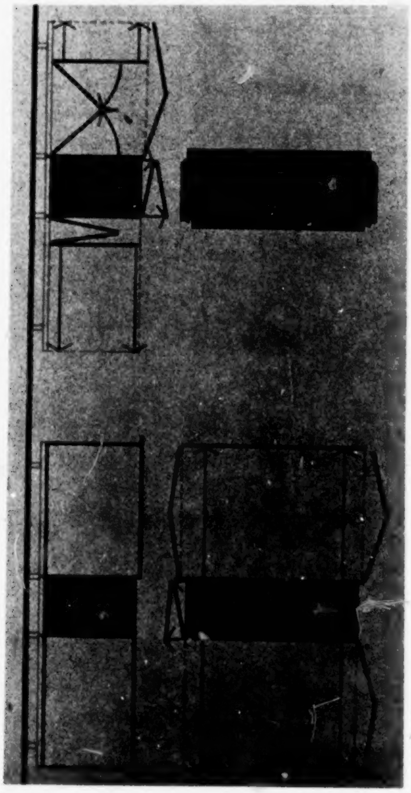
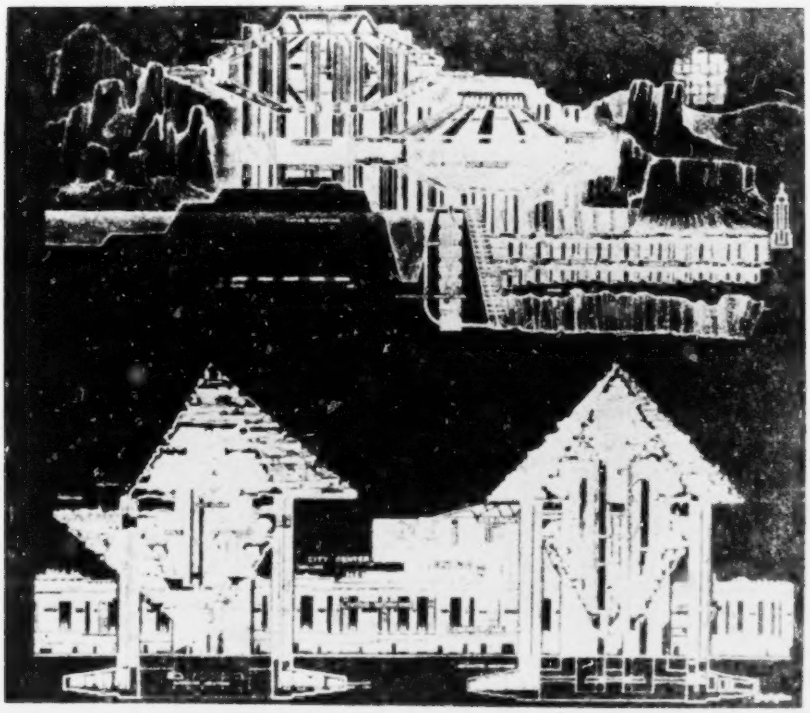


Figure 27. The Acron house [12].



Architect Paolo Soleri envisions future cities with [illegible] people living in vast multilevel structures like these, dwarfing the Empire State Building, shown to scale right of top drawing.

Figure 28. Arcology [13].

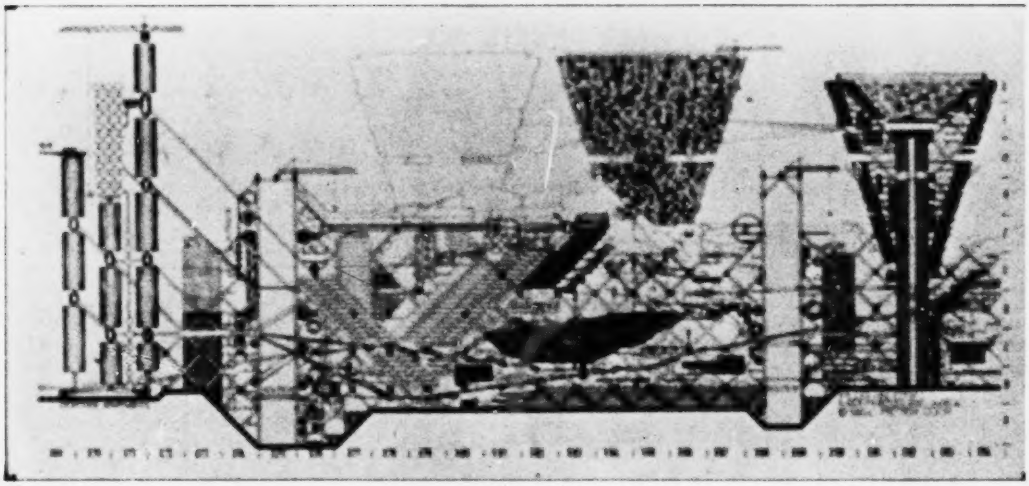


Figure 29. Plug-in city.

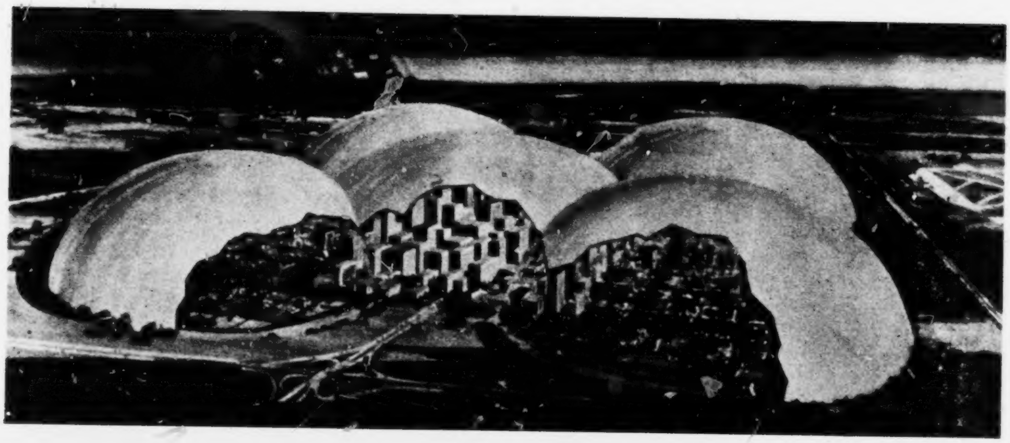


Figure 30. Super-roof structure.

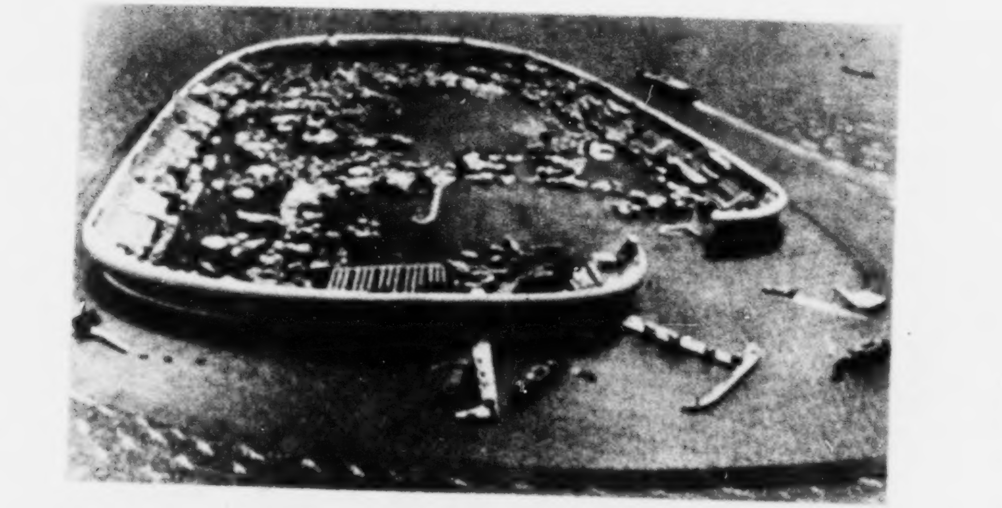


Figure 31. Sea city (courtesy of Machine Design).

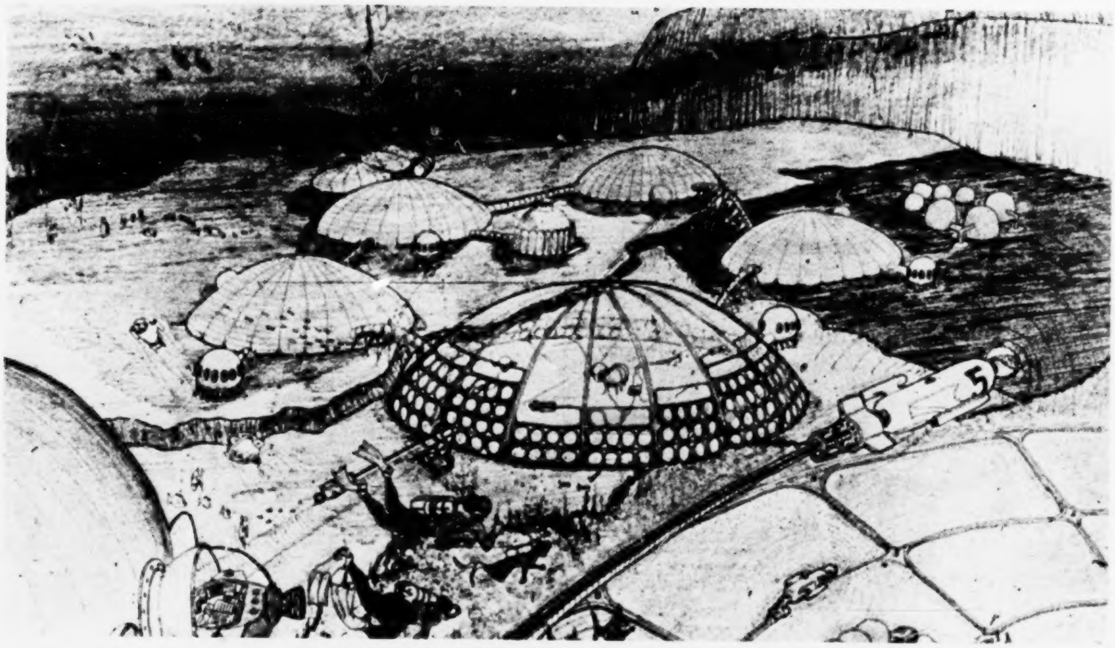


Figure 32. Undersea community (courtesy of Progressive Architecture).

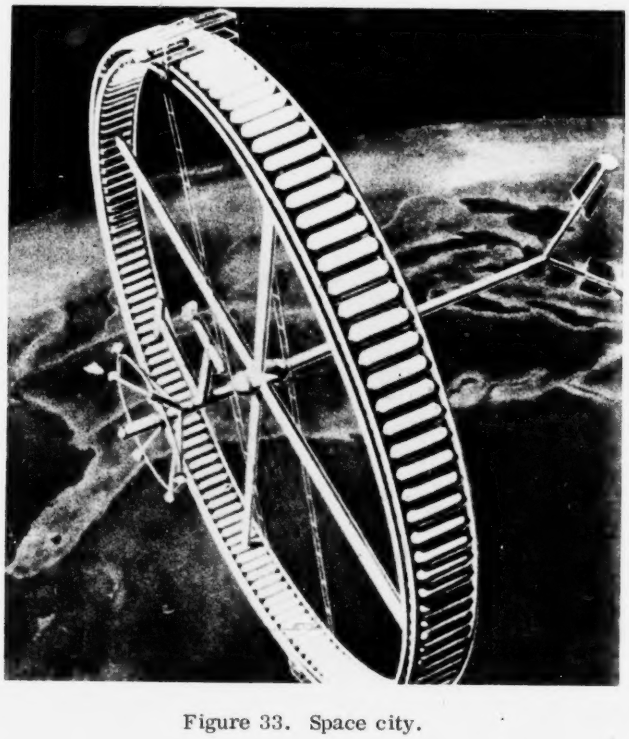


Figure 33. Space city.

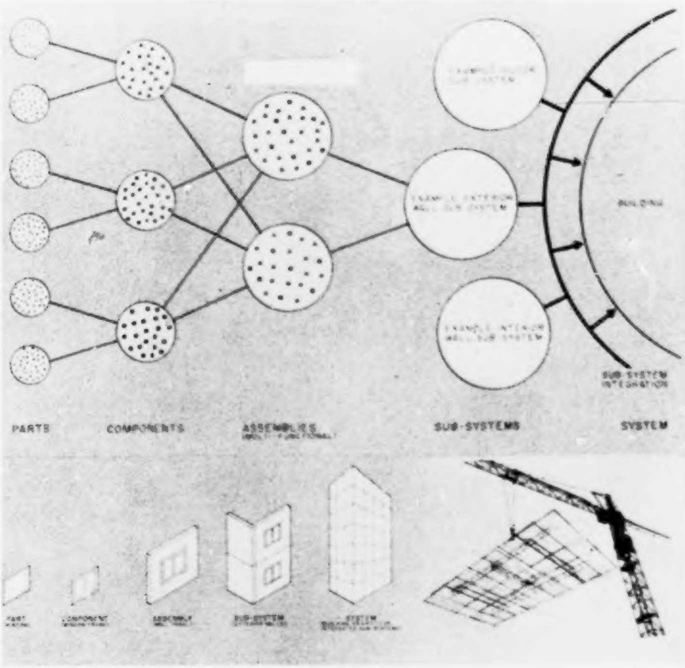

EXAMPLE EXTERIOR WALL SUB SYSTEM
EXAMPLE INTERIOR WALL SUB SYSTEM
BUILDING
SUB-SYSTEM INTEGRATION
PARTS
COMPONENTS
ASSEMBLIES
SUB-SYSTEMS
SYSTEM

Figure 34. Systems definition (courtesy of Progressive Architecture).

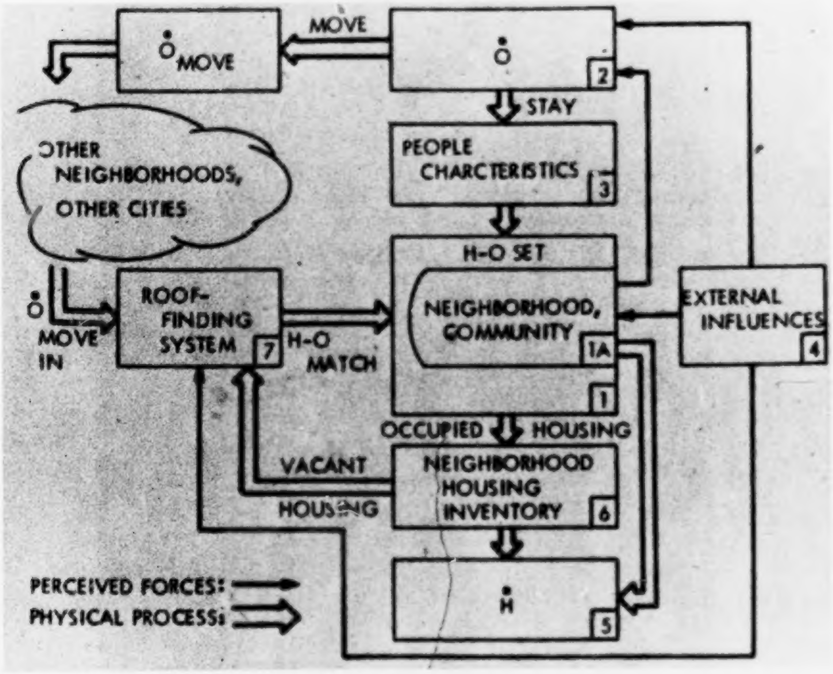

MOVE
Ȯ MOVE
Ȯ
2
STAY
PEOPLE CHARCTERISTICS
3
OTHER NEIGHBORHOODS, OTHER CITIES
H-O SET
Ȯ
MOVE IN
ROOF-FINDING SYSTEM
7
H-O MATCH
NEIGHBORHOOD, COMMUNITY
1A
1
EXTERNAL INFLUENCES
4
OCCUPIED
HOUSING
VACANT
HOUSING
NEIGHBORHOOD HOUSING INVENTORY
6
Ḣ
5
PERCEIVED FORCES:
PHYSICAL PROCESS:

Figure 35. Major elements of the housing system [21].

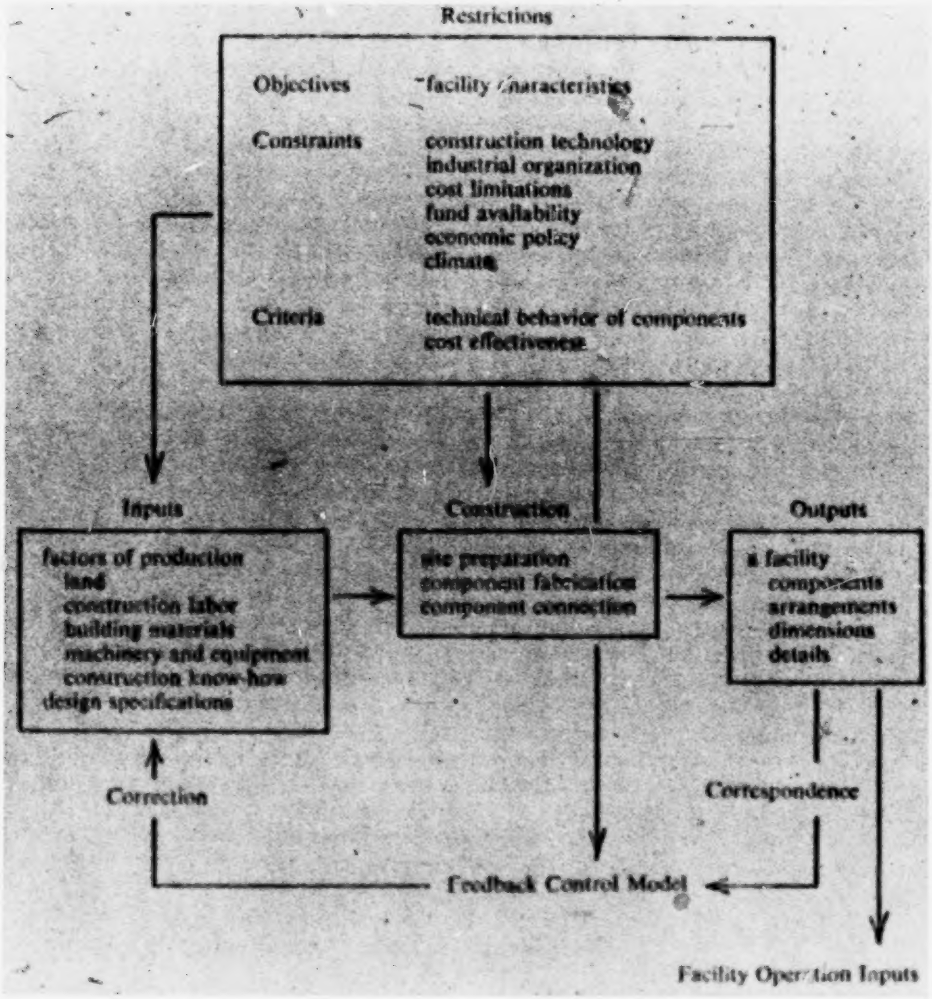

Restrictions
Objectives
facility characteristics
Constraints
construction technology
industrial organization
cost limitations
fund availability
economic policy
climate
Criteria
technical behavior of components
cost effectiveness
Inputs
factors of production
land
construction labor
building materials
machinery and equipment
construction know-how
design specifications
Construction
site preparation
component fabrication
component connection
Outputs
a facility
components
arrangements
dimensions
details
Correction
Correspondence
Feedback Control Model
Facility Operation Inputs

Figure 36. Structure of the construction subsystem [20].

# BENEFITS TO BE DERIVED FROM METEOROLOGICAL SATELLITE TECHNOLOGY

By Dr. Delbert D. Smith
Professor and Legal Advisor
Space Science and Engineering Center
University of Wisconsin

## Introduction

The ultimate user of satellite technology had been relegated to a position of relative insignificance in early developmental programs, because of great pressures at a domestic and international level for successful technical results. Even where the user was considered, it was primarily concerning benefits derived from technological spillover. Now this situation has changed, and an attempt is being made to insure that the full benefits of satellite technology reach the general population. But this is not an easy task. In a sense, it becomes an exercise in the "linking" function, attempting to determine and correlate users' needs with the technology required to fulfill these needs, and then to shape the development of future technology.

At the Space Science and Engineering Center of the University of Wisconsin the above approach has been undertaken in two areas: communication and meteorological satellite development. It is the purpose to briefly set forth the efforts that have been undertaken in these two fields.

## Educational Satellite Development: An Approach

While advances in satellite telecommunication technology promise to revolutionize global communication, it is not certain that educational uses of such satellite systems will develop concomitantly. Educational uses may be relegated to obscurity while our society utilizes the more spectacular and commercially viable facets of the medium.

A relevant question for satellite development becomes: What if the medium really is the message? What if the communication satellite, which is a tremendous new medium, becomes the ultimate message? To avoid this outcome I suggest that there is an ethical responsibility which must be assumed by those charged with the development and utilization of communication satellites and also, by those in our universities who must apply the knowledge obtained from their respective disciplines for optimal use of communication satellite technology. It is necessary to examine the various ramifications of the technology, while resisting developmental programs, which do not deal with the software problems and possibilities that should, in fact, establish prerequisites for hardware design.

While commercial satellite development, and particularly, the signing of the definitive International Telecommunications Satellite Consortium (INTELSAT) Agreements, revolutionizes worldwide telecommunications, there are also educational needs and related specialized needs in areas, such as law, medicine, and government services that must be explored. There is a presumption in favor of the desirability of widespread utilization of satellite telecommunication in conjunction with commercial radio, telephone, television, and data transmission, but there is no such presumption regarding an educational satellite system, whether global, regional, or domestic.

In the U.S., the Federal Communications Commission (FCC) is considering proposals which would allow private corporations to develop domestic satellite systems in conjunction with existing ground communications facilities. Within these proposals there is little said regarding educational usage of the system. This is an area where detailed arrangements and plans should be formulated if educational users are to be accommodated.

Some of the less-industrialized countries of the world are considering the possibility of national and regional communication satellite systems, which may prove to be the best means of expanding presently inadequate terrestrial communications facilities; but they, too, lack a full understanding of such a system pertaining to education and the need for in-depth feasibility research.

At the World Administrative Radio Conference (WARC), which this writer attended this past summer in Geneva, frequency allocations were considered for a wide variety of space activities. Of particular interest was the worldwide allocation at

2.5 GHz for educational purposes. The implication of this allocation is that there will be significant domestic and regional educational uses of communication satellites. Thus, it is necessary for educators and government officials responsible for educational planning to develop educationally viable satellite experiments, which contain evaluation components. The Rock Mountain satellite experiment and the possible Appalachia experiment are pointed in the right direction, but much more needs to be done if the potential of the satellite is to be realized as a medium for education at a distance.

If satellite technology is to fulfill its promise, its development must be guided by carefully defined humanistic purposes and priorities. There must be an objective assessment of the limitations and capabilities of the new communication satellite technology in meeting our expectations. Often we proceed under the illusion that, merely because it is technically feasible to develop a given satellite system, it is reasonable to expect that the system will function successfully in pursuing the goals we have set for ourselves or for our national development. There are many components of any major technological system, and usually the least complex of these is the technical one. Perhaps most often overlooked is the question of social feasibility, and particularly, of users' needs. Assuming that a satellite system can be built, is there reason to believe that it will be accepted and used as anticipated by the people for whom it is intended?

Another vital problem relates to the effectiveness of the system once it has been accepted and is being used. If you wish to design a satellite system to serve the teleconference needs of legal educators, for example, to what extent will this means of communication effectively replace, supplement, or improve the conventional techniques of the face-to-face conference? The question of effectiveness applies to most educational and social communications processes, which have been suggested as communication satellite activities, and can be determined only by conducting in-depth feasibility studies in particular discipline areas. We need to learn more about the consequences of utilizing communication satellites. To do otherwise would be, at best, irresponsible and, at worst, disastrous.

## The Educational Satellite (EDSAT) Center

At the University of Wisconsin, the EDSAT Center has undertaken the study of the educational and social applications of satellite telecommunications, coupled with the development of the necessary hardware systems. The Center is a multidisciplinary facility with a satellite transmitting capability, which focuses on problems relating to satellites and their educational and social applications. The main objectives of the Center are:

1. To provide a focus for multidisciplinary research and training in the educational and social applications and impact of satellite telecommunication

2. To develop working models for the application of satellite telecommunication systems to educational and social problems

3. To develop and maintain a satellite transmission and reception capability which will allow for an integration of hardware and software research

4. To serve as an information clearinghouse for the collection, annotation, and dissemination of information relative to the educational and social applications of space telecommunication.

The location of the Center within the Space Science and Engineering Center of the University provides immediate access to scientists, technicians and engineers so that our software research does not lose touch with reality and we are able to maintain an effective multidisciplinary approach to our work. In addition, representatives from the fields of international development, anthropology, law, education and mass communication help to maintain a significant humanities input.

### Research and Training

Center research interests focus on the inter-institutional, problem-oriented applications of satellite telecommunication and the potential of satellites in education. Research areas of special interest include:

1. Satellite teleconferencing: information exchange and data transmission with links between institutions, administrators, and scholars in multidisciplinary, national, international, monocultural, and cross-cultural settings

2. Satellite telecommunications in teaching-learning activities: the uses of satellite telecommunication in the context of other educational media and their broader educational and social implications

3. Telecommunication law: the stimulation and development of studies with special emphasis on international telecommunication control and the need for relevant international treaties and agreements

4. Evaluation and assessment: the design and testing of means for the evaluation and assessment of the social and educational impact of satellite telecommunications.

The Center provides research facilities to established scholars concerned with problems relating to the educational and social applications of satellites, and involves foreign scholars in research and training operations.

### Development of Models

A user-oriented approach is applied at the EDSAT Center which utilizes feasibility studies and other means in determining the most beneficial satellite system configurations. Based on the results of research generated at the Center and in the field, working models are developed which can then be adapted by others, in cooperation with EDSAT, to suit their particular needs and circumstances.

It is important that hardware and software be regarded as integral parts of the same total system, neither of which can be applied in an unrelated fashion. To the extent that software development precedes and shapes hardware development and uses, it becomes possible to develop a hardware technology which is user-oriented and which consists of equipment of a specialized nature developed in response to users' needs.

Further, the Center is attempting to determine, by hypothesis, demonstration, testing and evaluation, models for teaching and learning that will be effective in expanding the scope of multicultural adult education. These models will examine the use of satellites as a component of a broad-based system of information diffusion.

### Telecommunication Law

In addition to models for the development of hardware and software, the Center also conducts studies to establish legal and organizational models to serve as the basis for eventual national, regional, and global communication satellite systems. The complexities of such systems may in some cases require the creation of new institutional bodies or special national and international legislation to deal with the problems involved.

Further legal research has been undertaken pertaining to the need for changes in the International Telecommunications Union (ITU) to enable it to deal more effectively with problems arising in the satellite broadcasting area, and concerning the need for revision in international copyright law. Many of the problems that will arise at the 1973 ITU Plenipotentiary Conference are also under study.

The legal implications of the Definitive INTELSAT Agreements have been analyzed at the Center and an analysis of the domestic satellite offerings is currently being made with emphasis being given to the provisions being made for educational access.

The educational and legal implications of Cable Television (CATV) development are also being studied, and the roles of the Office of Telecommunication Policy and the FCC are being considered. This research is considered necessary inasmuch as CATV promises to provide a means of local distribution for satellite signals.

### Experimental-Demonstration Laboratory

The Center's experimental-demonstration laboratory operates under an experimental radio license with FCC call letters KB2-XML. Equipped with two Motorola base station transceiver units (110 watt and 400 watt) and a Cushcraft Model A144-20T antenna, the Center has full voice and data transmission and reception capabilities. The base station is designed for remote-control operation permitting transmission, reception, monitoring, and control from various locations. EDSAT Center transmissions are made at 149.22 and 149.25 Hz and receptions at 135.6 and 135.62 Hz. All activities thus far have been conducted via Applications Technology Satellites (ATS) I and III which are used by permission of NASA. Future transmissions will be at 2.5 GHz and participation in ATSF-G experiments is anticipated.

### Information Clearinghouse

The EDSAT information clearinghouse provides for the collection, annotation, and selective dissemination of information. After initial selection, the information is made available through the publication of special bibliographies. The clearinghouse has developed a continuing in-house bibliographic service to meet the information needs of the Center-connected research personnel in the U.S. and abroad.

In May 1970, the first EDSAT bibliography was published, titled, "The Educational and Social Use of Communications Satellites." A second entitled "Teleconferencing" has been published and our first annotated bibliography entitled "The Legal and Political Aspects of Satellite Telecommunication" has recently been made available. An annotated bibliography on conferencing and teleconferencing as related to future telecommunications trends, and a bibliography on the adult learner are in the printing process.

Further, the Center is developing an information network in cooperation with United Nations Educational, Scientific, and Cultural Organization (UNESCO) which can utilize the resources of other institutions, domestically and internationally, in pursuit of common educational goals. There is a need for a consortium of universities and research institutions to become involved in research and the exchange of information in the area of educational satellite usage.

We are also aware of the technological changes that have brought about new concepts pertaining to information exchange. The areas of information transfer utilizing existing technology for services, such as medical diagnosis, high-speed transfer of data, teleconferencing and data retrieval, are all being given research consideration. Again our research in these areas is user-oriented, attempting to ascertain both the perceived needs and the future demand for a specific service, within the context of the necessary legal regulations. It is hoped that this research and experimentation will have a positive effect on governmental decisionmakers in coming years.

## The Communication of Meteorological Satellite Data to User Groups: The Need for a Multidisciplinary Approach

While the applications of educational satellite broadcasting activities present a wide variety of problems covering areas of educational policy and related areas, the utilization of meteorological satellite data presents a more precise parameter. The spin-scan camera in the meteorological satellite produces a photograph which is enhanced and interpreted with the result being information that a person can use to determine his activities for the day. The more accurate the information is, and the less the amount of time elapsed between the taking of the picture and the dissemination of the information, the more desirable the system. In order to determine the optimum dissemination system and the sensor configuration for future meteorological satellites, NASA-sponsored research has been undertaken by the Space Science and Engineering Center to determine users' needs.

### The Research Design

The approach of the multidisciplinary team, in this area, was to begin with the user and to work back to the meteorological data, in order to be able to make suggestions as to the design and development of future satellite systems. It was considered important that meteorological satellite system development be responsive to users' needs, since, ultimately, it is the satisfaction of these needs that justifies the system. Such a system should possess the ability to respond to a wide variety of users, who will be increasing in number, and it should also be able to serve a wide variety of users who have both general and specific needs. In addition, there should be an ease of access to the data and sufficient flexibility in the system to enable it to change to meet new needs.

One difficulty in trying to develop an optimum system is that the users who might benefit from an improved forecasting service are not ordinarily self-motivated to seek the data. The mass media have been used to some extent to increase the availability of the data, but no attempt has been made to ascertain from the media viewer whether this is what he really wants and needs.

Data that originate with the satellite is altered in form as it proceeds from its source to the general public. One of the first users of satellite data is government and other scientists, who have the greatest effect on the alterations to be made in the satellite data acquisition systems. Since the data are altered and processed before reaching the general public, it becomes difficult for the average person to suggest changes in the quality, or quantity, of information that he is receiving. Specifically, users of weather data are not aware of any possibility for improving their weather information and thus they do not attempt to initiate any changes. In fact, there could even be some user resistance to change, which has to be overcome by making the user aware of opportunities that could be made available through the new satellite technology.

What we are determining is not only user needs but also user behavior. By utilizing the expertise available in various disciplines, we were able to analyze this behavior and thus come to a truer picture of actual needs. By including agricultural specialists in user-oriented research, not only were we able to ascertain users' needs but also to determine unarticulated needs which the satellite can fulfill. The use of field studies to determine users' needs and, specifically, the analysis of the behavior patterns of users when interrogating a weather distribution system for information were the best techniques for this purpose. By using the additional techniques of oral interviews, questionnaires, and meetings, we were able to optimize our research findings.

Therefore, it was one of our research parameters that not only should the user be made aware of the best way to use satellite data, but also, there should be a user input which would contribute to the best development of the system: in this case, the meteorological satellite.

The values to be gained through user-oriented research include an improved use of our natural resources, a reduction of damage to people and buildings from natural disasters, economic gain in agricultural and other sectors, a reduction in uncertainty, and a greater ease of planning for various sectors of our society.

There is also a time factor involved in any user-oriented study. When we first made contact with various user groups, we received an initial response. To a large extent, this response was based on a complete lack of knowledge or understanding concerning the satellite. As we proceeded with our interviews and other forms of user contact, an education process was taking place. Users' needs were actually being created. The awareness of the possibilities of the satellite created needs in areas that had not been given any prior consideration. In this sense the researchers acted as "linkers" between the user and the originator of the data.

The concept of a linking function, which has been utilized in the communications theory for some time, provided for us a focus for the collection of data relative to users' needs. Our subject matter experts served an educational function as they translated the technical terms associated with satellite weather data to the various user communities. In the course of our research we reaffirmed our feeling that the existence of the data does not insure its utilization, and that a comprehensive linking function must be present.

The major divisions within our case studies were (1) natural resources utilization and impact, (2) agricultural impact, and (3) commercial activities impact. Experts in these areas undertook individual case studies to determine the nature of the impact of weather-predicting capabilities, provided by the meteorological satellite program, upon their area of special concern. They detailed, where possible, the annual cycle of human activity in their area and identified those times when weather affected their operations. The characteristic effects wrought by weather variations, the type and cost (if any) of preventive measures which might be taken as a protection against adverse weather phenomena, and the benefits derived from this protection were estimated.

Each case-study investigator described how the weather and the availability of precise weather prediction information affected the activity he was studying.

Generally, each case study was undertaken according to the following outline:

1. The activity to be studied was described.

2. The weather-sensitive features of the activity were identified.

3. The functional relationships between weather phenomena and weather-sensitive features were described.

4. The economic implications of this relationship were ascertained.

5. The potential economic benefit of weather information, available from currently used weather-gathering methods, were compared with the potential economic benefit to be gained from fuller utilization of the meteorological satellite program.

### The Legal Study

Various independent studies were undertaken in conjunction with the case studies in this multidisciplinary project. An independent legal study has examined the national and international effects and ramifications of the U.S. meteorological satellite program. The focus has been upon the impact of this program on political and international affairs, and the nature of the international cooperation, which has stemmed from the development of the U.S. weather satellite program. Emphasis has been placed on the implications of the use of satellites in conjunction with sensors, such as constant altitude superpressure balloons and ocean data acquisition systems. The fact that the existing international law in this area is minimal has given increased significance to this work which considers both the state of the current law and the alternatives available for a future legal regime. The interactions between the law and technology have been presented, and consideration has been given to an analysis of the relevant international legislation, the applicable safety regulations, the question of liability, and the need for possible international agreements. The legal problems relating to the multiplicity of uses of satellites have been considered, as have been mechanisms for the dissemination of information from meteorological satellites.

Further research in this area will stress both the need for international legal rules in the area of satellite meteorology and the need for the development of domestic law to deal with the interpretation and utilization of satellite meteorological data. An analysis of the question of legal liability for the use and applications of satellite meteorological data will be of particular concern. Also included will be a section on the law of evidence relating to the use of meteorological photographs in courtroom proceedings.

## Preliminary Findings

Weather sensitive parameters. While there was found to be a significant information gap, we also found that there were inarticulated needs that satellite meteorology could fulfill. Even though some users were completely unaware that meteorological satellites were even existent, it was apparent that the two-culture separation that existed could be bridged by undertaking detailed analysis of users' needs. From these case studies we found that there are weather-sensitive parameters for about 80 percent of the users studied, and there are substantial economic benefits to be obtained from increased weather information in the majority, that is, 70 percent of the cases studied. The existence of these weather-sensitive parameters provided a first cut for our research and indicated that further work would prove valuable. Thus, in order to evaluate user requirements in detail and to assess the impact of improved weather information, whether from the present origination and distribution system or directly from a meteorological satellite without any system in between, it was necessary to look into each case study area in some detail in order to extract the relevant information.

The case studies clearly showed that different weather parameters can be critical along the path from beginning to completion of the activity and, also, that the time scale required for the user to react in a useful way, also varied over wide limits. It appears, thus, that the best way to meet user needs would not be to produce highly detailed data far in advance. To do so would simply transfer the data storage and retrieval task to the user. Users' needs are specific, both in time and data content. Predictions of those weather parameters which affect long leadtime items are needed well in advance of the weather, but when short reaction time is possible, the user actually would prefer being advised at a later date. In general, large-scale weather phenomena can be predicted further in advance than can smaller scale phenomena. There is a tendency for users' needs to correspond with forecast capability, but, unfortunately, this is not always true. If the occurrence of smaller scale phenomena, such as hail, could be predicted sufficiently in advance, crops could be selected at planting time to avoid loss. Put another way, it may be argued that users' needs adapt to forecast capabilities only because other forecast options have not been offered. A specific finding of our work shows that even very short-range information of severe weather (hours rather than days) has significant economic value. One need not provide any predictive information at all in this situation, since merely communicating the present weather in some detail would be sufficient if it were received in a timely manner.

Key information flow. Still another finding of our work thus far emphasizes the need for a "linker" in the overall weather information gathering, dissemination and utilization process. This individual must know enough about meteorology and about satellite observing systems, as well as the needs of the user, to be able to enhance the key information flow. We emphasize the words "key information," which refer to data which are necessary in the operation of a weather information service and is also critical in the design of a meteorological system.

The dual need for key weather information can be illustrated with two examples, one requiring medium-range and the other short-range information:

1. The case study concerning the hay crop showed a very large potential economic benefit ($ 88 million for one crop, in one state, in 1 year) if a 3-day spell of no rain could be predicted near the hay crop flowering date, in early June. This crop needs a 3-day, no-rain period to dry after it is cut. The protein content of the crop is sharply reduced if the crop becomes wet after cutting. In looking at this statement in detail, we learn that what is really needed is the specification of an effective drying index. Three days with no rain but extensive cloud cover may not be as effective as 2 days with no rain and bright sunshine. Since in the summertime the satellite can easily indicate extensive clear, sunny areas, it becomes apparent that satellite meteorology could have a significant impact in this sector of our agricultural economy.

2. With vegetable crops there is a need to predict calm wind conditions for spraying operations. Except for very flat pressure gradients usually found near the center of a high-pressure area near calm winds, it is almost impossible to predict calm wind conditions from gross weather features alone. In the Midwest a calm or light wind condition can exist in early evening, even with fresh winds a few hundred feet above the surface, provided the sky is clear. Surface cooling by strong back radiation stabilizes the atmosphere and decouples the surface layer from the windy layers above. Satellite cloud images, particularly IR images, provide the key information needed here, and, thus, could improve the economic situation for another agricultural area.

It would be unrealistic to expect every agriculturalist to become an expert in quantitative boundary-layer physics and be able to derive the key information needed himself, although he is an adequate amateur micrometeorologist from experience. Thus, a linker is needed to interpret what could be available and match this to the expressed needs in order that the agriculturalist be able to reduce his costs and maximize the benefits.

Most of the cast studies show several similar specific short-term information needs, and this area of weather data dissemination is clearly identified as needing additional study, both to establish the impact of the requirements on the design of meteorological satellite systems, and also to project the greatest benefit to the user. In this continuing multidisciplinary study, we are building on our current findings to proceed back along the chain from the user to the satellite in order to be able to suggest the optimum design of the meteorological satellite system.

## Conclusion

In both educational satellite communication and meteorological satellite data dissemination there is a need to more fully develop an appreciation of users' needs and requirements. In the former, the educational process must be explored and related to the technology. In the latter the weather-sensitive parameters and key information flow must be isolated and this information used in turn to help increase the use of the system. In each case the information obtained will help to determine the configuration of future satellite systems, the interface between the hardware and the software in the system, and the optimum application of the data from the system, whether it be educational programming or meteorological information. The result will be a more responsive and user-sensitive satellite technology.

# POWER WITHOUT POLLUTION

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Energy is being recognized as the limiting resource in an industrial society. While demands are being made to increase energy production, the potential impact on the environment and the exhaustion of natural resources, associated with present and planned production methods, has caused demands to be made for a reappraisal of these methods. Viewed on the time scale of human history, exhaustion of the world's fossil fuel will be but an ephemeral event lasting a few centuries [1]. This rapid exhaustion of our basic fuel can be readily understood when one considers that the world demand for electrical power is doubling about once every decade, and is expected to continue to do so until living standards throughout the world have been equalized and some form of population control has been achieved.

At the present, all efforts to meet the energy crisis are keyed to a single energy source, nuclear power, and to a single technology, the fast breeder reactor. However, other options need to be explored so that each major potential energy source, fission, fusion, geothermal, tidal, oceanic or solar, can be put into perspective with its more conventional competitors.

The source of energy within the nucleus of an atom is certainly large enough to provide for future large-scale power generation needs, whether it be released by the fission of certain heavy isotopes or by the fusion of the lighter isotopes. Also, this energy source may yet make man independent of other terrestrial energy resources. However, the deleterious effects on the ecology of the earth are now being recognized as possible limitations on this source of energy. In fact, the ecological consequences of the presently known sources of energy represent the most important obstacle to an increase in the generation of power and its associated industrial activities in the future. The ecology of the earth simply may not be capable of sustaining, or even tolerating, the growth of power generating capacity so long as power plants are based on the principles of thermodynamics and have to utilize the surface of the earth or its atmosphere as a heat sink or as a repository of its waste materials. Because of these potential consequences, serious consideration is being given to reducing the rates of industrial growth and thus achieve a period of stability. However, slower industrial growth has in it the inherent danger of cultural regression.

This uninviting prospect is based on the assumption that there is no alternative energy source and that the conversion of an energy source into its most useful form, electricity, is limited in efficiency to that possible through the Carnot cycle. Direct energy conversion, which invokes the principles of quantum mechanics and which relies on the solid-state behavior of materials, opens up new ways to tap the energy source which has sustained life on earth, the sun.

Utilization of the sun's energy is an old dream [2-6]. Solar energy has long invited collection and conversion into other useful forms, such as mechanical and electrical power, but past attempts have not shown enough economic promise to find widespread application. Recent developments in science, particularly in solid-state physics and in applied technology — as exemplified by the complex hardware required for space exploration; by advances in photovoltaic conversion of solar energy; and in the generation, transmission, and conversion of microwaves to generate power — add a new dimension to the concept of pollution-free power from solar energy.

The primary advantage of any large-scale use of solar energy is the inherent absence of virtually all of the undesirable environmental conditions created on earth by traditional means of power generation. Which of the approaches, now being proposed for large-scale conversion of solar energy [7-10], will become the most feasible alternative to present power generation methods, remains to be established. Therefore, efforts to provide details on various methods of converting solar energy to power should be recognized as worthy of increasing attention.

## Concept of a Satellite Solar Power Station

One approach is based on the concept of a satellite solar power station. An artist's concept of a system of such satellites placed in synchronous orbit with the earth is shown in Figure 1. Each satellite consists of arrays of solar cells to collect and convert solar energy to electricity, a transmission cable to supply the electricity to microwave generators, and an antenna to beam the microwaves to a receiving station on earth, where they could be converted to electricity (Fig. 2).

A synchronous satellite in an equatorial orbit will remain stationary over a point on the earth's surface. It would be exposed continuously to the sun, except near the spring or fall equinoxes, when it would be eclipsed by the earth for a maximum of 1 hour 8 min. These short periods of nonexposure can be overcome by using at least two satellite solar power stations, each displaced in an orbit from the other. Another solution would be to place the space power station in a nonequatorial orbit with a seasonal rhythm pattern. The satellite power station would no longer remain stationary with respect to the earth's surface but would appear to move up and down the southern horizon with a 24-hour period, the swing being the greatest during the equinox period.

The electrical and physical size of a typical system are illustrated in Figure 3. The system is scaled to deliver 10 000 MW of electrical power to the earth, enough to supply New York City and its surrounding area. Based on a solar array efficiency of 10 percent, the solar collector would cover 25 square miles. The microwave power transmission system would be designed to operate at a wavelength between 10 and 20 cm so the beam of energy would penetrate the earth's atmosphere with a very low loss, even under adverse weather conditions. A transmitting antenna, 1 square mile in area, designed for operation at a wavelength of 10 cm, and located in synchronous orbit 22 300 miles from the earth, can be designed to focus 99.9 percent of the generated microwave energy into a 25-square mile area on the earth's surface [11]. Outside of that receiving area, the density of the incident microwave energy will be negligible. Even within the area, the collection of the microwave energy will be so efficient that with the possible exception of the immediate center of the area, grazing animals, for example, would be unaffected by the microwaves.

The microwave power transmission system consists of three major parts:

1. Microwave generation, the conversion of the dc power output from the solar cells into microwave power

2. Beam forming, focusing the microwave energy into a sharp beam by means of the transmitting antenna

3. Microwave collection and reconversion to electrical energy.

High efficiencies have already been demonstrated in all three segments of the system [12]. Additional development effort promises to raise the conversion efficiencies at both the transmitting and receiving end to 90 percent. While the efficiency of microwave beam transmission can be raised to virtually 100 percent, cost considerations would probably indicate some lower efficiency. Nevertheless, the transmission efficiency would still be far in excess of any comparable conventional earthbound power transmission system.

The power-handling capacity of a transmission link in free space is virtually unlimited. Furthermore, it can be upgraded by adding additional elements to the solar cell array, additional or higher-powered conversion elements at the transmitting end, and higher-powered elements at the receiving end. Neither the area of the transmitting antenna nor that of the receiving device on the ground needs to be increased. Thus, a system, once installed, has ample opportunity for power growth without the need for additional real estate on the earth.

At first glance, the very high power levels associated with the system do not seem to be consistent with a microwave technology, usually identified with the lower power levels common in the communication industry. However, high-power tubes with high efficiencies have been developed and await applications [13]. To be sure, no single tube now available can supply 10 000 MW of microwave power, but even if one were available, it would not be used. Transmitting antenna construction and service reliability are more likely to favor the use of several thousand transmitting tubes on a one-phase array. Such an array would reduce the rating of the individual tubes to the point where their design would be consistent with a modest extension of existing tube technology.

What if we should need transmitting tubes with individual ratings of a magnitude two or three orders greater than those in existence? Very likely, they could be designed by taking advantage of one or more recent developments. The availability of samarium cobalt as a permanent magnet material, for example, permits an order-of-magnitude decrease in magnet weight for microwave power generators.

The power-handling capability at the receiving end is based on a device called the rectenna [14]. This device is nondirective and can be made in the form of a lightweight web supported on posts. It uses highly efficient Schottky barrier diodes, whose efficiency and power-handling capability are being improved continuously.

The satellite solar power station and the microwave power transmission system would use considerably less copper than would a traditional power generation facility of an equal power rating. Hence, the solar space power station would help conserve this and, perhaps, other critical materials.

A system of space power satellites could provide a nearly inexhaustible source of electric power. A belt of solar cells 3 mi wide in a synchronous orbit around the earth would intercept $1.68 \times 10^{15}$ W of solar energy. Even if there were no improvements in solar cell efficiency, 8 percent of this power, or a total of $1.34 \times 10^{15}$ W, could be made available in the form of dc power to widely distributed locations on the earth. Such a power level would provide $1.17 \times 10^{15}$ kW-hour of electrical energy per year, or more than 200 times the projected world electrical energy requirements for the year, 1980. As conversion efficiencies of solar cells and of other system components were increased, satellite solar power stations would be able to keep up with increasing world energy demands.

Such a huge potential for electrical power generation might well provide the necessary leverage to conserve our fossil-fuel sources of energy, now used, not only for electrical power generation, but also for many other energy requirements.

## Systems Considerations

System engineering and management techniques, developed to direct and control massive engineering undertakings, have contributed heavily to the success of the space program. The development of a satellite solar power station would have to call on these techniques to determine the size and capacity of each component of the system, to predict the performance of the assembled components for the various system configurations, to estimate the dependency of the performance of the component charac-

The major components of the system (Fig. 3) will have to be well defined, the components identified as to function and type, the sequence in which they are connected established, their functions analyzed, and the differences among various approaches reconciled. Although candidates for most of the components now exist, at least in the form of laboratory models, new and quite different components can be expected to be developed. How each will perform if fully developed is uncertain, but systems engineering techniques can be used to approximate and compare the performance and costs of the various system configurations, to estimate the dependency of the performance of the component characteristics, and to set quantitative targets for component developments based on forecasts of component technology and performance.

A reusable space shuttle is expected to result in significantly lower costs for orbiting payloads in the 1975-1985 period. As envisioned, the Space Shuttle will be capable of carrying payloads of 50 000 lb. Succeeding generations of space transportation systems would be expected to have substantially greater payload-carrying capacities. Over a period of several months, a Space Tug, powered by ion engines, could transport to synchronous orbit modules of a satellite station that had been assembled in a train in a low earth orbit. Alternatively, a reusable nuclear stage could be used to transport the modules between low earth orbit and synchronous orbit.

The concept of a satellite solar power station rests on the availability of an efficient and economical space transportation system. Its successful development over the next decade will depend on solving many technical problems that are being addressed in our efforts to place large manned space stations in orbit. Thus, the capability to produce large structures in space, which will be essential to assembling the modular space stations envisioned for future missions, should be available during the next decade [15]. The experience gained in the assembly of such large structures by human operators, subsequently, with the help of automated teleoperators, will be a step toward a satellite solar power station.

## Technology Status

Solar Energy Conversion. Silicon solar cells have been the primary source of electric power for almost all unmanned spacecraft, both for space exploration programs and for the application of space technology to communications, navigation, and meteorology. Improvement of the technology of silicon solar cells has been accelerated by the increasing requirements of large spacecraft for missions in earth orbit and for exploration of the planets. Solar cell arrays have grown from a few square feet, to the lightweight deployable solar cell arrays of several thousand square feet, and power levels of tens of kilowatts now being applied in the Skylab spacecraft.

The N/P silicon solar cells, with their superior radiation resistance and good control over mechanical and electrical tolerances, have been the mainstay for space missions. New processes, such as the manufacture of solar cells from webbed dendrite silicon or from extrusion of a ribbon of silicon single crystals, are expected to increase the cell size, and thus, reduce cost, especially for the large solar cell arrays. Lithium-doped silicon solar cells have the potential of providing a fiftyfold improvement in radiation resistance over the conventional N/P silicon cell [16]. Rollout solar cell arrays with a specific power of 30 W per pound, within the state of the art and further improvements can be anticipated [17].

The most significant long-term opportunity is for a major advance in photovoltaic efficiency. While the single-transition silicon solar cell is theoretically limited to efficiencies of 25 percent, with about 10 percent attained in practice, solar cells with higher efficiencies are possible. A multicellular device, for example, consisting of two or more photovoltaic layers in a sandwich configuration, could use wavelength bands where the materials have high quantum efficiencies and thereby increase overall efficiency considerably. Attained efficiencies of 20 percent are considered feasible in the near future [18].

Organic compounds which slow characteristic semiconductor properties, including the photovoltaic effect [19], have only recently been considered as possible energy conversion devices. At present, their efficiencies are only a fraction of a percent, but efforts are underway to synthesize polymers with good photovoltaic characteristics and to study the behavior of other organic compounds [20].

Transmission of Electrical Power. Electric power produced through photovoltaic conversion will have to be gathered at the solar collector and transmitted to the microwave generators. The high power levels may require that the transmission line be superconducting to reduce weight and power losses. To transmit $10^7$ kW (20 kV at $5 \times 10^5$ A), for example, would require two conductors of a 2-in. diam cooled to about 15° K, and each suitably insulated. The state of the art of thermal insulations for this purpose is well advanced, and proper design would reduce heat losses to a minimum [21]. Multiple-staged refrigerators would provide the desired temperatures over the length of the transmission line. At the superconducting temperature, 1000 W of refrigeration capacity would be sufficient to cool the line and to absorb heat leaks at the cable ends. Such refrigerators have already entered an advanced development stage and would be adaptable for this purpose.

The transmission line, itself, would have to be articulated to provide relative movement between the solar collector and the antenna. The solar collector will have to be approximately pointed at the sun, while the microwave radiating antenna will have to be accurately beamed to a receiving antenna on earth, thus relative motion between the solar collector and the antenna will have to be provided. Rotary joints at the warm end of the transmission line with low friction and capability to carry the power would have to be developed. Experience with movable joints, their lubrication requirements, and the influence of the space environment on frictional characteristics would provide bench marks for this development [22].

Guidance and Control. The large structures which will have to be guided and controlled, particularly the antenna required to beam the microwaves to earth, will require that the state of the art of guidance and control systems be extended to achieve desired position control. The pointing requirements for the solar collector which will have to face the sun are less stringent. Combinations of sun sensors, or star trackers could provide the desired pointing accuracy of about 1 deg. Except for the size of the structure which has to be controlled, the types of devices required are within the state of the art.

The microwave beam will have to lock onto the earth-based receiving antenna and to stray less than 500 ft in any direction. A perimeter of land 1 or 2 mi wide surrounding the antenna may be necessary to assure that the microwave power density not absorbed by the antenna will be below stated limits outside this area. This is desirable, not only to maintain a high efficiency for transferring microwave power, but also to assure environmental safety during operation. To achieve this accuracy would require pointing the microwave radiating antenna to about 0.5 sec of arc. Although this requirement stretches the present limits of attitude control techniques and pointing accuracies, the significant advances in guidance and control over the last decade indicate that this technology could be extended to meet the requirements of a satellite solar power station.

A guidance and control system will have to deal with the forces acting on the satellite to maintain a circular orbit. Among these is the radiation pressure acting on the solar collector and, to a lesser extent, on the antenna. The force, in a direction opposite to the sun, on the solar collector, will be about 300 N; this force will be partially averaged out during an orbit. The force in a radial direction away from the earth, on the antenna, will be about 200 N; this force would have to be counteracted with thrusters. Gravity gradients will introduce a torque about an axis perpendicular to the equatorial plane, as long as a circular equatorial orbit is maintained. Counteracting continuous angular displacement will require thrusters. High specific impulse could be achieved using ion engines, which would be an outgrowth of present technology [23].

Cooling Equipment. The microwave generators will have to be cooled, because heat is generated at the cathode and the anode of each generator. The amount of heat is a direct function of the efficiency of the generator system. If a multiplicity of small microwave generators is used, the generated heat could be removed by means of heat pipes or space radiators distributed over the structure of the microwave radiating antenna. The efficiency of the heat pipes and space radiators would affect the overall weight of the satellite structure significantly. The technology of heat pipes, for instance, has been advancing rapidly and projected weights of 0.1 lb/kW appear to be feasible [24]. The state of the art of coatings and thermal insulations to attenuate and control the flow of heat has advanced to the stage where it can be thermally controlled.

Detailed designs and concepts for a satellite solar power station have not yet evolved to the point that firm cost estimates can be made. However, the first step toward this goal can be taken by projecting from the present state of the art in the direction that future developments may have to take. The assumption can be made that a system of satellite solar power stations should be capable of providing a significant portion of U.S., and eventually world, energy needs. Thus, the design and development of components will require that they be mass produced on a very substantial scale. This is in sharp contrast to present techniques and the resulting costs associated with the production of space flight hardware.

Should the option for energy production based on satellite solar power stations be found to be desirable, the establishment of an industrial base, not unlike that existing in the consumer electronics and the automobile industry, would be a result. The satellites lend themselves to mass production because there are only a few different types of components. Production will involve the replication and assembly of large numbers of components, such as solar cells, microwave generators and microwave rectifiers. In an optimum design, the structure of the satellite will largely be formed by the components and the required electrical interconnectors.

Major components may be assembled in synchronous orbit with assembly techniques, perhaps, based on the use of automated teleoperators. Certain of the components could be formed in an orbital assembly facility to utilize the low-gravity conditions to fullest advantage. Similarly, once in orbit, materials and components could be refurbished; e.g., annealing of solar cells, to extend their operating life. The development of radiation resistant materials, such as solar cells, indicates that the space environment will be more benign than the terrestrial environment, with its continued physical and chemical eroding processes acting on solar energy conversion devices, and 30-year lifetimes for solar cells can be projected in space.

The twin goals of design for mass production and extended operating life are a strong indication of the potential for substantial innovation, as work on a satellite solar power station progresses. A number of analogous advances in technology have taken place as the need for innovation in certain areas was recognized. Examples are the 10 percent efficient solar cells, developed in 1953; the first payload orbited, in 1957; and the first transmission of microwave power, in 1963. Should technical, economic, and social feasibility studies indicate that satellite solar power stations deserve a major effort, the development time of about 20 years would not be unlike that required for nuclear power development.

Cost projections, based on an extension of presently known technology, indicate that a satellite solar power station would generate power at two to five times the cost of competing power generating plants. Additional developments may reduce the presently projected cost differential. However, before meaningful cost comparisons can be made, it will be necessary to arrive at a method of cost accounting, which establishes true environmental and social costs chargeable to each energy production system, rather than comparing systems only on the basis of capital costs and interest.

## Conclusion

The large-scale use of solar energy to generate power without pollution could sustain a highly energy-dependent world culture for much longer than the few centuries associated with fossil fuels or, perhaps, even nuclear power. The potential for making this option available to meet future energy demands will be influenced by continuing efforts to advance space technology. There is a risk that exclusive concern with contemporary problems and short-term solutions, without regard to the future, could lead to a deemphasis of space technology and foreclose the large-scale use of solar energy by satellites.

As yet, it is too early to state what bets should be placed on this option to produce power without pollution. What is required, therefore, is a program of research and development to resolve outstanding technical, economic, and social issues, and to place this concept for using solar energy into perspective with respect to both conventional sources of energy and its more exotic competitors. Only with this information in hand can actions be initiated to develop energy sources consistent with a coherent national policy designed to meet future energy demands [25].

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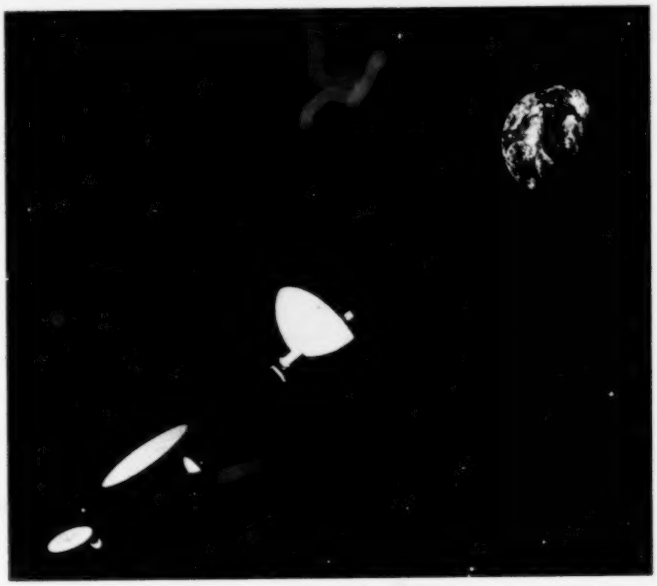


Figure 1. Artist rendering of satellite solar power station.

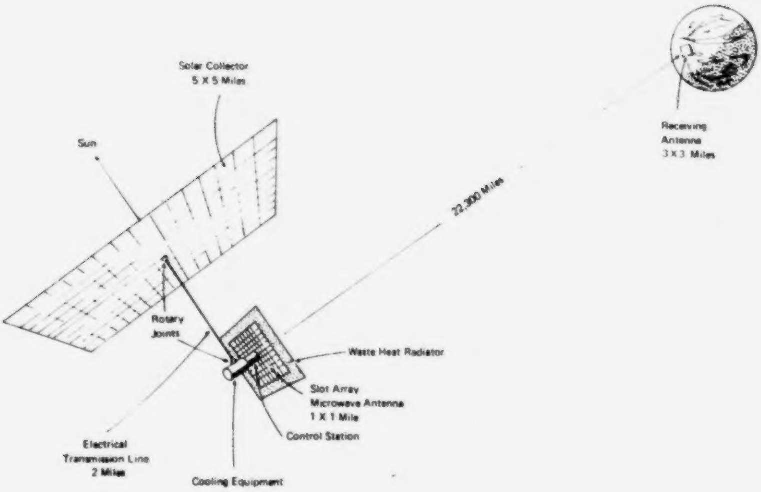
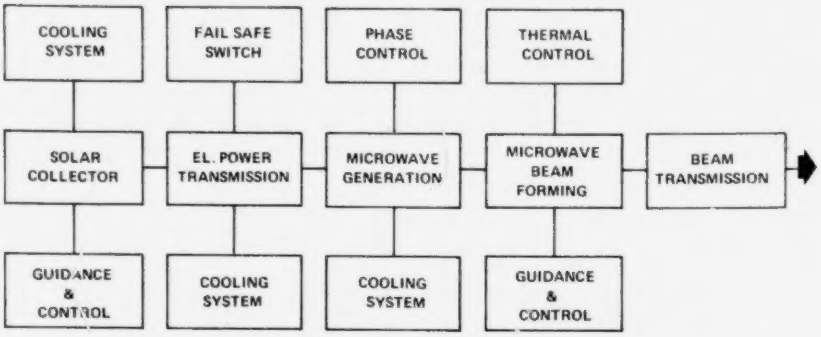
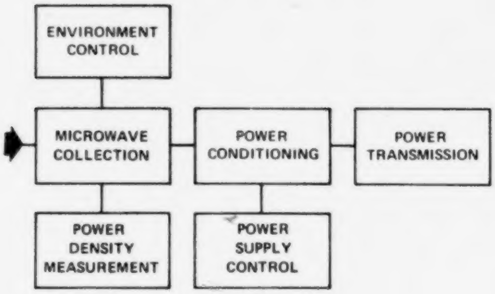

Solar Collector
5 X 5 Miles
Sun
Receiving
Antenna
3 X 3 Miles
22,300 Miles
Rotary
Joints
Waste Heat Radiator
Slot Array
Microwave Antenna
1 X 1 Mile
Control Station
Electrical
Transmission Line
2 Miles
Cooling Equipment

Figure 2. Diagram of satellite solar power station to produce 10 000 MW.

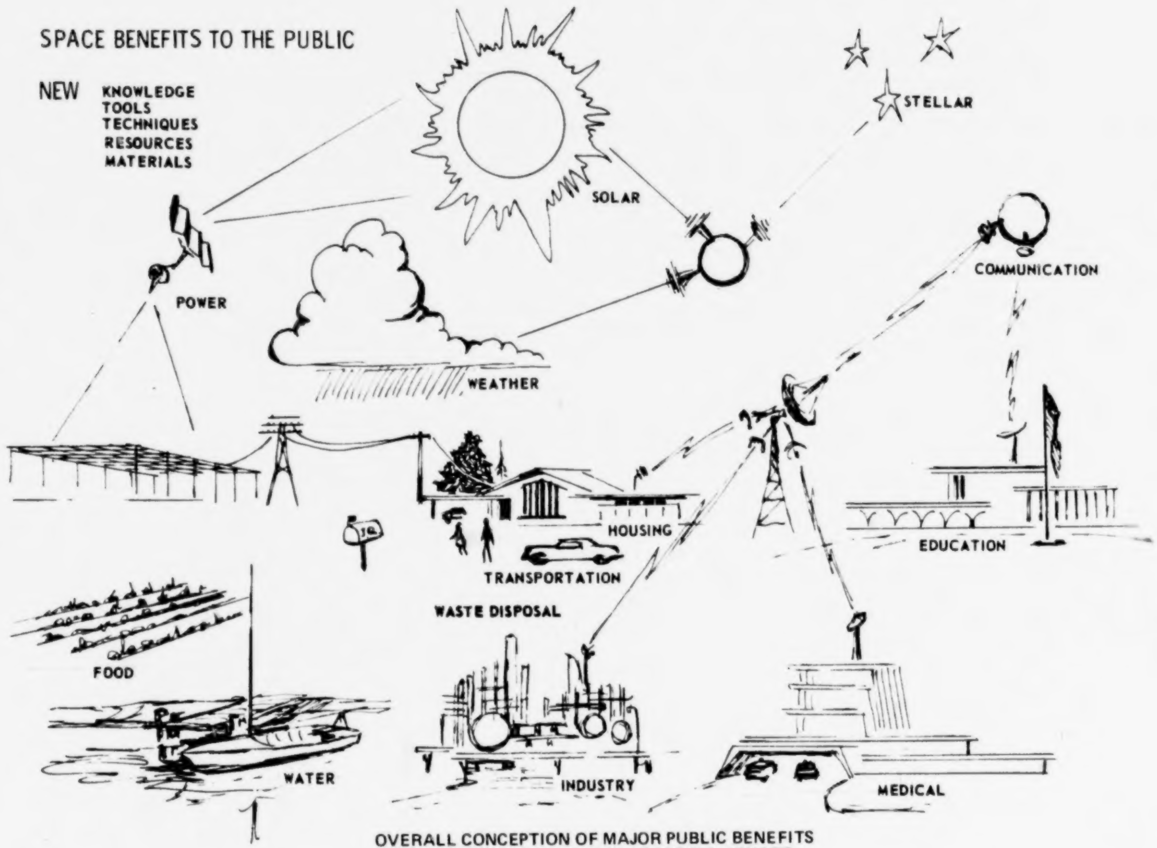

COOLING SYSTEM
FAIL SAFE SWITCH
PHASE CONTROL
THERMAL CONTROL
SOLAR COLLECTOR
EL. POWER TRANSMISSION
MICROWAVE GENERATION
MICROWAVE BEAM FORMING
BEAM TRANSMISSION
GUIDANCE & CONTROL
COOLING SYSTEM
COOLING SYSTEM
GUIDANCE & CONTROL

A.
SATELLITE
STATION


ENVIRONMENT CONTROL
MICROWAVE COLLECTION
POWER CONDITIONING
POWER TRANSMISSION
POWER DENSITY MEASUREMENT
POWER SUPPLY CONTROL

B.
GROUND
STATION

Figure 3. Major components of a satellite solar power station.


SPACE BENEFITS TO THE PUBLIC
NEW KNOWLEDGE
TOOLS
TECHNIQUES
RESOURCES
MATERIALS
STELLAR
SOLAR
POWER
COMMUNICATION
WEATHER
HOUSING
EDUCATION
TRANSPORTATION
WASTE DISPOSAL
FOOD
WATER
INDUSTRY
MEDICAL

OVERALL CONCEPTION OF MAJOR PUBLIC BENEFITS RESULTING FROM THE SPACE PROGRAM. (CHART COURTESY OF D.L. CHRISTENSEN)

# SESSION X

## SOCIAL BENEFITS AND INTERNATIONAL COOPERATION THROUGH SPACE

# THE POLITICAL AND LEGAL ASPECTS OF SPACE APPLICATIONS

By Dr. John Hanessian, Jr.
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The George Washington University

My first attachment with space affairs, which happened rather suddenly, occurred back in 1954 and 1955, when I was with the National Academy of Sciences in Washington. I was the first staff member to be brought in to deal with something called the International Geophysical Year. We had no money, just a couple of borrowed desks and some rather grandiose ideas. Two of these were, first, we might borrow some Navy ships and go to Antarctica, and second, we might talk somebody into an outer-space program. A couple of years later, very much to our surprise, we were able to do a number of these things.

I still remember with considerable clarity the day Wernher von Braun walked into our office — it must have been in 1954 — and said, "Gentlemen, you have been talking about outer space and all these things. We have a rocket down there in Alabama, and I think it will do the job for you." We had a very lengthy discussion with him and were very impressed with his presentation, but unfortunately the government was not. Instead, they went ahead with a completely different program with the Navy — and you are all familiar with the Vanguard story.

I would like to discuss some of the political and legal aspects without trying to get into the jargon that some of us use in the international legal community, but trying to bring up some of the points that are rather urgent and important, many of which are not often accepted by governmental agencies as being relevant to the kinds of problems that they have in terms of engineering requirements and launching.

With this beginning of the second decade in space, it is my feeling and it is probably shared with others, that a major shift of interest is taking place. I would like to pinpoint two areas in which this is happening. First, during the sixties, as you know, the United States and the Soviet programs concentrated on manned space exploration, with some attention to science and applications. In the future, I think it is already beginning to happen, there will be greatly increased interest on applications and a considerable decrease in public attention, at least, on the importance and the funding of manned programs.

The second major shift that we think is happening is that, during the fifties and sixties, the U.S., the Soviet Union, Europe, Japan, etc., concentrated very much on a competitive development of national capabilities. It was the political competitiveness of the effort that finally convinced President Kennedy that we should go ahead with the race to the moon and the whole beginning of the Apollo program in this country. There was some international activity in these past 10 years, particularly in the areas of meteorology and communications. But still, the greatest emphasis was on this terribly wasteful competitive nature of what we had been doing. We feel that there will be a significant change in the next couple of decades here. That change, I think, is going to bring in more international interdependence, more international cooperation and perhaps, even some multinational programs as we go along. Most of these developments are going to be centered on the applications of space programs and particularly on the benefits that they can bring to people on earth, in the economic and social spheres. It is this kind of thing, we feel, that the public is going to be willing to pay for, and not so much for expeditions to Mars and that sort of thing. This is in no way detracting from the value of space missions; I am simply trying to pull it down to what, I think, the public is likely to support.

There are a number of reasons for these shifts. The first one, as I have already mentioned, is cost. When the public was told that it cost $25 billion to go to the moon, and then, when somebody did some computations on how much it would cost to bring each pound of rock back from the moon, without going into any of the other aspects, like technology utilization and so on, there was a very large cringing on the part of the American public which, during the same period, was required to pay over $100 billion for the war in Vietnam. The public sees an end to this kind of expenditure. They are much more concerned these days in using our public finances to help things out a little bit, here on earth. A second reason for this is one that may be difficult to explain, but we have had considerable writing on this and a lot of discussion, and many of us feel it is the way things are going; the way electronics and technology are going. As a matter of fact, one of the writers has coined a new word here. He calls it the Technotronic Age. The feeling here is, that as this kind of age continues there will come a greater need for international cooperation. It is something that we all have talked about before. We say, "it is a fine thing," we pay lip service, we pray before the alter of international cooperation, but governments in the past have not really been that concerned. It is national priorities and national needs that have been first. The way things are going, individual nations cannot do this anymore. There is an interdependence, a very great degree of interdependence, and it is going to force countries to adopt certain changes in their programs.

A third element responsible for this change is a rapidly growing awareness by the public of the need for global conservation of resources, and for global environmental management and global management of the exploitation of our resources. For the first time, we are beginning to realize that we are going to run out of things. We are going to run out of fossil fuels in another 100 years. And we are going to run out of clean air, perhaps, if we do not start doing something about pollution. The point which is relevant is, that the public is finally aware of all of this. They finally feel that the only way that you can lick these problems is to do it on a global or worldwide scale. This is something new.

Finally, there is a growing awareness, even on the part of some of our Congressmen, that you have got to do something about the developing countries. There is much confusion here. There is also a technical term that we have developed in recent years, which is called the North-South gap. North-South does not mean much, except that the more developed countries are in the north and most of the underdeveloped countries are in the south. Essentially the term was coined to differentiate the problem from the East-West problem; the confrontation, which existed for 20 years, between the U.S. and its friends. But this North-South gap, the gap in the gross national product, or the gap in living standards between the developed countries and the developing countries is increasing. This is the problem. The average income for the American is increasing much faster than the average income for the African or the Southeast Asian, although theirs is going up, too. However, the gap is growing. Unless something is done about this we are going to have a society in this country, in the next 50 or 60 yr, that is going to seem Buck-Rogerish compared to what is going on in the middle of Africa, or Southeastern Asia. The point here is that we can no longer look at this problem in an esoteric or philosophical way. We are too tied up with each other; we need them and they need us. Lest this sounds too idealistic, let me put it this way. The United Nations system has, I think, seized upon this point as the focus of most of its activities. There are limited opportunities in the United Nations for peacekeeping. The Security Council has its problems; we do not quite know yet what it is going to do with Peking in there; it may help, it may not help. In any event, several years ago the whole United Nations shifted a little bit. They said, "We can only do so much in peacekeeping. Let us turn our attention to the real problem of the world, which is how to help the developing countries." In the Outer Space Committee, in the General Assembly, in its subcommittees, and in every meeting that has taken place in the United Nations on outer space, the one theme that runs right through everything is, "How can this program help the developing countries?" It is always there! In fact, this past year they have appointed an individual in the United Nations Secretariat who has a title which is unique in the history of international organizations. His formal title is "Expert On Space Applications"; he has to sign his letters that way after his name. His whole job and the only reason he was appointed to this position by U Thant directly, is to set up and maintain relationships with developing countries; to try to show them how they can participate in space programs; and how, particularly, the Earth Resources Survey program, that we will get started next year, can be meaningful and useful to them. It is a big job. He has the cooperative relationships with 50 or 60 countries and he travels around. Dr. Fiorio and I are going to join him in Brazil for a meeting which the Brazilian Government is cosponsoring with the United Nations. The whole focus of the meeting is on how can a space program, like the Earth Resources Survey Satellite, be of use to a developing country. They have practically invited all of the Latin American countries there.

The United Nations conducted a meeting in Vienna 3 years ago. It was the first rather big meeting trying to explain space applications, not to the public this time, but to diplomats, heads of government, and Foreign Ministry representatives. The idea was that if the experts could get up there in front of an audience full of diplomatic types, somehow or another, space applications could be explained and this point could be made — "Look, Representative from a little country, you should be interested in space. Get your people going there, get your geologists and meteorologists interested in this so that you can participate and receive benefits from space in the next 10 years." It was a very tough job, and it was the United Nations' staff in New York that did all the work for this. So it is beginning.

In the last 10 years, whenever you went to another country and talked space, the reaction was, "Oh well, this is something that the United States and the Soviet Union spent billions of dollars for, and they go up there, do things, come back, and that is about all." Occasionally, you can tell them that some experiments are performed and they did hear a little bit about communications, but that was about it. It is a tremendous job now to try to get these countries to be involved themselves, in programs related to outer space. We made a terrible mistake 10 years ago when we put all this attention on manned space flight, too much of it. Now we have got to go back and start getting reinvolved again. It is a very, very big operation. These diplomats did not understand. They said, "I do not see how that satellite up there is going to help my farming problem and my country." It took many hours of patient explanation to tell them about remote sensing and how this can, in fact, help his farm with infrared photography.

On the subject of politics and legality problems that I think we are going to be faced with, I will mention, very quickly and superficially, some of the primary principles which have been accepted at the international level, primarily through the leadership of the United Nations, and try to indicate why these are important. One of the first very important points was to try to figure out what the jurisdictional situation in outer space would be. We never knew, until 1967, what we were going to do, as far as legal problems in outer space were concerned. It was totally unclear, for instance, as to whether you could claim a section of the moon or whether you could not or what was to happen with it. The Daughters of the American Revolution and many other patriotic groups passed a resolution a few years ago that said, "As soon as the first American astronaut gets to the moon, the U.S. flag has to be there, and we claim the whole thing. It is ours." Well, the feeling on the part of many people was that this would have been disastrous because then you really would have had a rush between ourselves and the Soviets. Thus, essentially, there were three different points of view; first, "let us get there, claim this, and grab it" — then the opposite point of view was that perhaps outer space, including the Moon, Mars, and all the other planets, should be completely protected from exploitation in a political and legal sense. In other words, nobody could be able to claim them, whatsoever, and outer space would be open to all mankind. The Latin term that we use for this is "Res Communis." The third idea, pushed very hard by India, Egypt, Brazil and other developing countries, took an altogether different point. "No, no! We should internationalize all of these areas. The United Nations should be in control of the moon." This horrified the United States Government and the Soviet Government, both, so we did not quite get into that one. What was finally selected, and this is the 1967 Outer Space Treaty, was the second of these three rules; nothing in space can be claimed by anybody. It is totally free and it is to stay that way. The deployment of an American flag on the moon is only meant symbolically. It has no legal meaning and we cannot claim or own 1 in. of that territory up there. Thus, the common interest of mankind is one of the major themes that has been accepted. It is one theme that the United Nations pushes very hard.

A second theme, which is brand new in international politics and international law and which has disturbed and bothered the Soviets and the United States, is that there ought to be an equal sharing of space benefits. We do not know how to go about sharing space benefits. We can publish papers and send copies around to the world but is this really sharing it? The focus now is very strong on the point that every country has the right, not just a privilege, to benefit on equal terms, and I am quoting from the United Nations document, "regardless of the actual capabilities of individual states to acquire such benefits by themselves." In other words, it is now mandatory for the United States and the Soviet Union, France, or Britain or any other space power, to share the benefits of outer space with the whole world. It is very difficult to take that mandatory requirement and translate it into actual operation. We do not spend enough time or energy; nor do we see many system models put together as to how to share this. It is an obligation, however, that we have.

Another point that has bothered some people is something which I often call the Mafia Satellite. Now that we can get a satellite up there for a few million dollars, we are very much concerned as to what is going to happen when the Mafia puts together a launching facility. In the 1967 treaty there was some concern about this aspect; lawyers do get very practical, and they worried about this. So they put a very formal requirement into the treaty that, regardless of how a satellite or spacecraft gets up into space, the country from which it originates, the launching place, has total responsibility. Thus, if the Mafia launches from Chicago, the U.S. Government has responsibility.

A couple of years ago in Geneva, I attended a meeting of the Working Group on Direct-Broadcast Satellites of the United Nations. The committee was worrying about political and legal aspects of direct broadcasting; not so much about channels or frequencies or regulation of this and that, but about program content. Again, this is going to be a problem which engineers, technical people, or NASA is simply not going to be able to cope with. What we are worrying about is something which we call propaganda. Propaganda is a very big word, and can be a very dirty word. Essentially, there were two attitudes expressed at that Geneva meeting and unfortunately, it was the United States and the Soviet Union that were on opposite sides of the fence on this one. The U. S., as you know, is a strong believer in the idea, that he who puts up a satellite should be able to do what he wants with it. If we want to put up an Applications Technology Satellite (ATS) and use it for direct broadcasting purposes in India, then that is our and India's business, and nobody else should get involved in this. If someone else should happen to tune in on one of these programs, that is just too bad. It is not something that we really should worry about. This attitude is backed up further by a longstanding kind of human rights development in the United Nations, that everybody has the right to receive whatever information he wants. This is the anticensorship argument. If you want to get a Soviet newspaper, or a Chinese one, you should be able to get it. If you want to listen to these programs, you should have the right to do that. The Soviet Union took just the opposite side of this. They said, "This is horrible! Imagine the propaganda that is going to be sent around." They pointed out a couple of rather humorous things; for example they said that suppose Spain puts on a television broadcast of bullfighting and the Indians pick it up in India. There would be a national revolution or something. Then one of the Russians took me aside and smiled and said, "Look, do you think that your Congressman is going to approve any kind of a deal whereby your American public will turn on Channel 11 and there is Moscow?" He said, "I don't think so, and, by the way, I think that your deodorant commercials are terrible and we do not want that stuff in the Soviet Union." The point he was trying to make and, which was eloquently established by their diplomats, was that there should be, in the Soviet terms, censorship and control by the receiving government on any kind of broadcast from a direct broadcast system outside. In other words, each country and each government has the right to examine what broadcast is coming into the country and select out those which it feels are unfit for its people. Well, here are these two completely opposing arguments. They have not been resolved and will not be resolved for a while. It is one of the major problems that we have.

I think you are all familiar with what the Earth Resources Survey Satellite will be, and with the fact that the first launch will be made in Spring 1972. Essentially, we are going to have a satellite that will circle the globe, take infrared photography, send it to earth through television systems, and come up with color photographs which will enable the data processors and data users on earth to use this information for a number of economic and social purposes. There are problems here, and I will quickly discuss a few of these. The first of these, the one which NASA denies to exist as a problem, is the question of intrusion into territorial sovereignty. What do I mean by that? Well, here you have a satellite with a camera taking pictures of a country that maybe does not want to be photographed, especially when it finds out that the photography is going to come up with data which can be translated by another country or a real "hotshot" company into means by which it can be exploited, or where, at least, they will perceive a possible exploitation. They are going to say, "Sure, we have the photograph, but we will not know what it means. Meanwhile, the XYZ Company is going to come in here and grab something from us." So the perceived exploitation is an extremely important part of this; but there also is a legal question. Do we, the United States, the Soviet Union, or any other launching power, have the right to take pictures of a country and use those pictures for economic value? The reply NASA gave to this kind of circular argument is, "Oh well, there have been spy satellites around for years and nobody has complained about it yet."

The second problem with Earth Resources Survey Satellites is, who is going to own these data? You say, "All right, it is an American satellite, it is an American camera, and it is going to be an American data processing system." But who owns the information that is going to be on that photograph? Why should not the country that is being photographed have some share in this? And what about the point I made earlier, whereby we have an international commitment to share this information? Our government's response is very simple. They say, "Oh yes, anybody that wants the pictures can have them." But that is not sufficient here. How do we guarantee that everybody or every country has not only an equal share in looking at the pictures, but also equal benefits from utilizing the data that can be perceived from these pictures? We do not have any real mechanism yet for the international management of this program. It is true that NASA is prescribed by its charter to only engage in experimental programs; ERTS-A and -B are going to be an experiment. Later in this decade we are going to have an operational Earth Resources Survey program, there is no question about this Therefore, are we going to go into another long-drawn debate about the International Telecommunications Satellite Consortium (INTELSAT)? Is this the answer, a consortium of sorts? I doubt very much whether the countries of the earth are going to agree to another consortium, in which, for the first 10 years, the U.S. owns 51 percent. This kind of development is no longer possible. They are going to want a greater share of it right from the start, even if the U.S. is paying most of the cost. This is one of the hardest things to swallow for the U.S. and its government here.

Transcribed from tape

# SPACE EXPLORATION AND WORLD PEACE

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Until this century there was always some place on earth to explore and know fully. Men have climbed earth's highest mountain, walked upon the North and South Poles, and plunged the depths of the ocean. Man's determination to fully explore his native planet has finally turned him toward outer space, from which he can learn more about the earth and its surroundings, the sun and its radiations, the possibility of life on other planets, and the distant galaxies that lie beyond the Milky Way.

## The Meaning of Space

Space begins at the point where the atmosphere is so thin that it has no effect on anything in it; where meteors start to glow from friction against the air; and where the ionosphere ends, let us say, somewhere about 250 miles above the earth. This is our frontier. Beyond this frontier there is practically nothing. Space is a near-vacuum without air or sound.

Around the sun are nine major planets including earth; many thousands of minor planets which we call asteroids, a big family of comets; clouds or cosmic dust; and swarms of meteors. Between the various parts of our solar system is the void, which is another way of saying space. Gravity is the cosmic glue which holds the system together.

In spite of the fact that there are military and political reasons for the present urgency of the space programs by both the U.S. and the Soviet Union, a rich future can grow out of the very discoveries that people dread most — nuclear energy, automation, and biological advances, which are the most powerful social forces in this century. But these powerful social forces can be as great in peace, as in war; we can use them to create the future and not to destroy it. In space exploration, science promises a future in which men can lead intelligent and healthy lives — a future that is worth living for.

## Present Technical Knowledge

From a purely technical standpoint, we already now know enough to do each of the following:

1. Produce enough food to feed every hungry mouth on earth, even though the world's population should double or treble
2. Rid our cities' air of all forms of manmade pollution
3. Make fresh water out of sea water and thus irrigate all the world's arid regions
4. Transport large numbers of people or large quantities of material from any place on earth to any other, in a few hours
5. Produce enough energy from uranium to light and heat our homes and offices, electrify our railroads, and run all our factories
6. Establish instantaneous communication by telegraph, telephone, teletype, or television between any two points on the surface of the earth — and when the occasion arises, between any two points of the solar system.

## Scientific Space Development

Since the inception of the space program, it has been a policy, especially carried on by the U.S., to extend the benefits of space research "to all mankind," as required by the 1958 act. The American space effort has been conducted openly, and its results have been shared with many nations.

The global communications satellite network is a prime example of tremendous space benefits. Over 70 countries joined the U.S. in the International Telecommunications Satellite Consortium (INTELSAT), all of which are enjoying the benefits of this satellite.

In the same way, more than 40 nations are benefiting from improved weather forecasting, based on cloud-cover photographs relayed by a space system equipped with NASA-developed satellites. Many of these countries could not have afforded the elaborate ground stations, once needed to acquire and process satellite photos. Recently, developed prototypes of a simplified, inexpensive receiving station enable even the smallest nation to buy and use.

## International Benefits

To quote a few instances of international benefits derived from space programs, the U.S. and France combined their efforts to orbit a satellite to track hundreds of balloons, making it possible to chart, for the first time, the winds that circle the globe.

Through space programs, weather forecasting is becoming increasingly accurate. Satellites and weather are inherently global systems. By using automatic readout systems, every nation in the world can benefit from the Automatic Picture Taking (APT) systems on board U.S. weather satellites. Over 50 countries are now using this to daily view weather patterns over their own territory — a wonderful example of the use of space for the benefits of men everywhere. These same countries also benefit from cloud picture mosaics routinely made available by the Weather Bureau to Europe, Asia, Australia, and North and South America. The weather mosaic is built up from individual weather photos and processed by computer; it is then retransmitted from ESSA ground station via NASA satellites. This is a very real example of the combined benefits, national and international, that space systems are creating for the average citizen.

A joint United States - India project in mass instructional television is under development. In 1972 an advanced satellite known as Applications Technology Satellite-F (ATS-F) will be maneuvered into a stationary position over India where it can "see" some 5000 villages equipped with inexpensive community receivers built by India. From a few transmitting stations, the Indian Government will beam educational television programs, focused initially on population control and improvement of agriculture, to the satellite. ATS-F will then retransmit the programs to hundreds of thousands of people in the receiver-equipped villages.

New uses are continually being found for telecommunications. Banks, stock exchanges, hotel reservations, cable television, hospitals, computer centers, and other new customers are appearing at an increasing rate. As one recently remarked, space exploration is leading us "to a global communications explosion."

An example of new applications was provided, in 1970, by the 18th International Congress, for postgraduate medical instruction. The American doctors stayed at Houston and San Antonio in Texas; their counterparts were in Switzerland, Germany, and Austria. Satellites provided closed-circuit television and two-way voice circuits between the United States and Europe, enabling a reported 30 000 European doctors to hear and see the 3-hour transatlantic conference.

## World as a Unit

Space has made the world seem smaller, more delicate and precious. At the same time, it made man seem larger. Man can now look at his earth the way it truly stands — a tiny blue watery pebble that constantly roams in the silent abyss of the universe.

Since the race in space was started by Sputnik, over a billion children have been born all around the world, the first space generation. Today's children can look ahead confidently to new opportunities and to great new strides that man will make in the 21st century, when they will be in their thirties and forties. Their generation will view the earth as a whole for the first time and be able to deal with technology, science, and philosophy as a unified experience, common to all men of the blue planet, earth. This will certainly have profound educational consequences in relation to international stability and world peace.

When a generation learns to view the world as a whole, many individual and national problems would then be solved. Such problems will be approached in correlation and not in isolation. In correlation means considering similar problems that other individuals, other nations have and, in collaboration with them, try to arrive to a practical solution. What is the use of concentrating on curing a fatal disease in the arm when afterwards I let it develop in the leg? If the leg is amputated in consequence of neglect, the rest of the members of the body will suffer inconveniency as a result.

We are all members of the same species called the human race. Like the various members of the body we have various kinds of people in the human society. Some people have unique roles to play distinct from others. Yet all roles are important — each person in his own unique way. The eyes are certainly the most important member of the body in relation to the recognition of colors, and the ears are undoubtedly the most important member of the body in relation to the appreciation of music. However, certain parts of the body, such as the heart and the brains, are of vital importance. Although a human being could live without an arm or a leg, he is not expected to live without heart or brains. This means that in the history of human society there are certain members that are of vital importance. These members of society consist of those persons who are dedicating themselves thoroughly for the welfare of mankind. They consist of persons who developed, since early childhood, outstanding virtues that later enabled them to develop a sense of equilibrium, balance, and judgment, which is so badly needed in the solution of certain delicate problems at both national and international levels.

## Priorities in Education

Because of surmounting problems, we seem to have, in the world today, a race between education and catastrophe. If we all yearn to see education as the hopeful winner, then the time has arrived to reevaluate our educational needs and project a kind of education that transcends national, political, and ethnic boundaries.

Our view of man, in terms of priorities, has to be reevaluated. A human being is first a sacred person with a unique identity of his own. Second, he is what he habitually presents himself to be through his actions and purposes — a good, honest, reliable person, or a bad, dishonest, unreliable individual. In the third place, a human being is a man or a woman, with all his specific characteristics and needs that his sexual role develops in a rational and sensible society.

It was obviously in terms of such priorities and the kind of educational approach that urged President Kennedy to plead with the American people: "Ask not what your country can do for you, but what you can do for your country." In other words, let us ask how beneficial we can render ourselves to the human race, beginning with ourselves here at home. Or, to put it in the words of Senator Robert Kennedy: "Let us begin by healing the wounds from within." This remark, of course, could be simultaneously applied to every single country without exception.

## Reevaluation of Human Relations

Why does the source of educational chaos, revealed in tensions existent in national and international relationships, consist in the not-yet-solved problem of priorities? We simply have formed the habit of concentrating primarily on the unessential, with little regard to the actually essential.

A human being could be nicknamed American, French, Russian, or Chinese because of the fact that he was accidentally born in a global area that was in turn nicknamed America, France, Russia, or China. Hence, in our reevaluation of educational priorities, especially in terms of human relations, the nationality we carry, the political party to which we claim we belong, as well as the ethnic creed we embrace in our private and perhaps public life, should, for all practical purposes, be considered of secondary and not of primary importance.

In this way, the problem of communication in the realm of human understanding will diminish considerably. The conflicts that may remain among humans will then take the shape of those existent in the ordinary family. No matter how much brothers and sisters quarrel, litigate, and fight each other, they all end up eating at the same table and sleeping under the roof of the same house in protection and security.

Bringing people together to live in a brotherly way is an educational task of a large order. So far, education has not accomplished this desired perennial goal. People are brought together only after we learn how to break through national and international barriers. In this regard, President Nixon took a great step forward in the establishment of world peace when he lifted the ban from American people to travel to the mainland of China.

## Space as an Instrument of Peace

With a clear knowledge of space benefits on one hand and of educational needs on the other, we can now begin to realize that space exploration may perhaps prove itself to be the most effective instrument in procuring international understanding through improved facilities in worldwide communications, and through the building of an emotionally and socially stable society in the growth of a peaceful world.

When people of every nation learn how to correlate their problems to those of others, when humans in every country learn how to break the barriers that hinder communications, when all the people across every continent learn to view their earthly blue planet as a unit and a whole, then the time would have arrived when man's long quest for peace would bear the desired results.

We will certainly not be written down in history as members of the generation of peace, because of the short span of our lifetime. But we will go down in history as the generation that initiated the generation of peace. This will eventually be revealed in our wholehearted efforts in space exploration that slowly, but surely, will break the barriers of communications that exist through national, political, and ethnic boundaries. Through space exploration we will, as a matter of fact, look at our planet as a unit void of artificial boundaries set by man since ancient times; through space exploration we will eventually look at all people as humans who share the same needs regardless of their background culture; through space exploration we will finally look at ourselves as lucky members of an intelligent species with unique contributions to make for the welfare of mankind in this planet and hopefully elsewhere as well.

# APPLICATION OF COMMUNICATION SATELLITES TO EDUCATIONAL PROGRAMS

By Jai P. Singh
Research Engineer, Center for Development Technology
Washington University

In this report, I will discuss what communication satellites could do for education, what the current thinking is, what the experimental plans are, and what the problem areas are.

The communication satellite unfolds attractive, potential benefits for our educational establishments. It can provide wide distance access to a broad variety of information resources, beyond the capability of a single institution. In 1958, the U.S. was the first nation to put up a communication satellite. These potential benefits have not yet been realized in the U.S. Any variety of communication facilities have either been too costly or inappropriate for wide use by educational institutions. The proposed domestic satellite systems, currently under consideration by the Federal Communications Commission (FCC), do not offer any significant cost reduction potentials, as they are multipurpose and locked in the International Telecommunications Satellite Consortium (INTELSAT) III and IV type technology with the sole exception of two filings.

It is in this respect that Washington University has undertaken a NASA-sponsored project to define educational services which telecommunications satellites may help provide, and to provide the decisionmakers in the Federal Government with the design of systems for delivering these services in the U.S. In order to insure that the study takes into account all systems aspects - political, social, organizational, administrative, as well as economical and technical - the work has been undertaken by an interdisciplinary group of research personnel, representing a broad range of disciplines and skills. Most of our group is dominated by economists as well as political and straight types. The program directly relates to the purposes of the nation for focusing upon the potential development and application of space technology to help meet the needs of society in the fields of education. I think that we have taken a systems approach. Some people may say it is the user-oriented approach, and many other people could put it in different ways. The basic thing is to define what the U.S. educational needs and objectives are. I will come back to that, but first I will discuss the "how" that we hope the domestic educational instructional satellite system might develop.

First, you look into the existing situation or into the future and try to define U.S. educational needs and objectives; try to define the constraints and limitations, both political, technological, and administrative. What kind of a system is going to be acceptable; what is the feasibility of a centralized system? How much centralization do you need in the system? Then, you try to build up a requirement for a satellite system. That requirement is going to depend upon other competing terrestrial technologies that may be capable of delivering the same services. It would be a function of the technological environment, the research and development (R& D) in the communication satellite area, and it would be a function of available funding. You try to build up some alternate systems, and present the decisionmakers with a couple of different system designs, all capable of delivering different things. From this, hopefully, some systems would emerge, some decisions for future R& D would be made, and you would have a pilot operational system.

For a pilot operational system we do not have to have a dedicated satellite just for education. As you will see in the later part of this report, there have been a number of experimental systems, and you could use some of the packages on the Advanced Technology Satellite to test out some of the concepts. This, in fact, has been done, and in 1973, people will be looking at testing more advanced concepts. Eventually, we will have gained some experience with the pilot systems. We would then try to redefine our needs and objectives, and eventually our new experience, our new R& D would again enhance the technological involvement, and the cycle would continue, that is the approach that we have taken or the user approach, you might say. The basic question is, how do you define educational needs and objectives? This is not simple; it is not a meteorological satellite, where you could go to people and say, "OK, why do you need that information?" Everyone has a different philosophy for education. Everybody has a different vision of the role that technology is going to play in education. By technology, I do not mean satellite technology. Satellites are nothing but a delivery mechanism. We have to go to the basic level of technology, such as television, computers, data, and other things; the basic thing that is delivered, and there is no consensus. So what we have done in this area is that we have been trying to create a dialogue with the users, but not just mere dialogue, and not with a layman-type attitude. We have been trying to look into the economics of various services through satellites and trying to provide the users with some decisionmaking, with some groundwork on which he could base his decisions; what he could do with certain types of satellite technology, where satellites are going to be useful and where not, and what the future roles of satellites are in this country.

These needs and objectives could be divided into a couple of categories. As you know, the public television in this country is a part of education, a broad educational segment. Those people know what their needs are today, how many stations that they want to link, but they have not been able to do it because of the cost of the current facilities. They are extremely interested. They could tell you the solution pattern they want, where they wanted to originate their programs from, the states that they wanted to link, how they want to feed the television to the stations — but for instructional purposes, this is a very tough job.

The first thing to do is to conduct studies of the various technologies and media, such as television and computer area instruction and their facsimiles, and automated information retrieval for the libraries. The study should look at the current developments, status problems, and future potentials. It should also look into what the problems have been and try to forecast some demands for the future technology and media utilization in education. It must be defined as to what would be the keys to technology utilization in education. It will not be fair to say, "In this field and time, this is the range of utilization that we are going to have." The particular range will depend on what happened between then and now, on what kinds of major decisions have been made on the federal level and state level, and what kinds of new forcing functions are given there. So there would be certain keys to technology utilization, and you would build up a case; e.g., that range of utilization, that range of delivery that will be needed for that kind of environment. We will try to define conditions for achieving various utilization levels, and the impact of those utilization levels on education.

There will also be background studies on such problems as what people in this domain could accomplish with satellites, satellite-based delivery, and networking system. Estimates for satellite utilization have to be developed, but before we go to estimates, I would like to go back and discuss what some of the basic services are that a satellite could deliver. You could have two different types of satellites for education: one would be a dedicated educational satellite, a satellite completely devoted to education, and the other method would be to lease channels on a commercial satellite. As you know, the FCC has some eight domestic satellite filings under consideration. Various applicants, a number of aerospace companies as well as common carriers, have proposed using communication satellites for various things. The primary use is for point-to-point communication. We have here two options. Fixed satellite service is the service that we have seen in the international domain. It is point-to-point service; that is, service between relatively large, high-cost earth terminals, for point-to-point communication. However, there are two other types of services. One is a Broadcasting Satellite Service which would be capable of delivering television, radio, and other programs; primarily a one-way service to community installations. The cable television head-end that you encounter would be a community installation. Satellites will be able to bring a large number of channels directly to your cable television (CATV) head-end and to your homes. This is something that cannot be done with the broadcasting system, because of the limited frequency availability problem. This is a service people will use in the early eighties or mid-eighties, where satellites would offer an opportunity to bring the signal directly to the home. You have your television set, a special antenna, and a special attachment. All you have to do is to plug in that attachment between the television set and the antenna, and you will be capable of receiving directly from satellites.

The current designs for this system have already been demonstrated. If we are going to build some 10 000 receivers per year for a single channel, the unit cost of the attachment between television set and antenna would be $40, and if we made some 100 000, the cost would be something like $25 per unit. All these units have been demonstrated and built by Stanford University, NASA-Lewis, and by General

Electric. You will also need a receiving antenna, a dish-type structure which you can build with chicken mesh very cheap. The cost would depend on how big the dish is.

When the domestic satellite proposals were invited by the FCC, the FCC said that all the applicants should state very clearly what services would be offered to the educational broadcasting people and to the educational community. Of eight applicants, seven have very nicely defined their services as either yes or no for the educational broadcasting community. Only one filing has ventured into the area of instruction. AT&T/ COMSAT is saying, "We will not offer anything specific for educational broadcasters but we are willing to discuss the term, and if the commission thinks that providing free service to broadcasters is a public dividend, we will accept that position; we will provide them free service, but we will put the cost of that service on other users of the system." It is not free; somebody has to pay for that service — other users of the service will have to pay. Also, a major question for the FCC is, what is a public dividend? Is it providing free service to a specific community of users, or is it providing cheaper service to all users of that system? It is one of the burning questions. There are varied opinions. There has been a letter some time ago, by Mr. T. Whitehead of the President's Office of Telecommunications Policy, questioning the whole approach of providing a public dividend based on just for educational broadcasters.

So, there have been a number of offerings, which I will not cover in detail. The only ones who have come forward with something specific are Fairchild-Hiller, who have made substantial offerings, and MCI/Lockheed. There are also filings by Western Telecommunications and Western Union. They do not offer anything at all like AT&T, and Western Union is very much the same case.

We have primarily defined the role of the satellite in the instructional area. For instructional television, the main role will be direct delivery to schools, to broadcaster stations for redistribution, and to Instructional Television Fixed Service (ITFS). Alabama is one of the finest in this service, and they have a number of installations in the state; ITFS head-ends and cable television head-ends for further redistribution. The satellite delivers a large number of channels to various centralized points and from there to cable and other broadcasting stations for redistributing; it is a type of networking. Delivery of computer area instructions to small remote institutions, particularly those 70 or 80 miles away from a major metropolitan area, is another service. The satellite service, based on a small terminal operation, has shown that we could offer substantial benefits for these purposes if we go to high-powered satellites. Domestic satellites, which are relatively low-powered and multipurpose, are not capable of offering this service economically. Then you go the the computer resources, and one of the best things in this area is that there is a tremendous mismatch between the users and the computer resources. There are some segments of users, such as large institutions that have substantial resources, but some 45 percent of this country's institutions of higher education do not have any computing available to their students, for any purpose. A goal established by the Princeton Science Advisory Committee, in 1967, was that in 1971, they would like to see some 20 min of basic computer processing time available to every undergraduate student in this country. We are nowhere near it; we do not even have 5 min for all students in higher education. The ones who are suffering are the 40 percent of small institutions; some of them are private, and most of them cannot afford to justify a dedicated computer system for their own use. But linked with communication lines, they could justify a remote, centralized computing facility that they could share. So we have a number of users. Multiaccess, interactive computing, and batch processing is nothing but a delivery of our computing power to those schools. Computer interconnection is a new thing. It has been developing, and it is between the computers; that is, between very specialized computers offering very specialized services. It has all ready been implemented using terrestrial networks by the Advanced Research Projects Agency (ARPA) of the Department of Defense. It has been established in 20 institutions; a good many of them are educational institutions. The basic problem is the high cost of communication lines and their inappropriateness of carrying digital data. These communication lines were designed primarily for carrying voice communication. All the subsequent improvements have been on that basic fundamental.

The Corporation of Public Broadcasting, NASA, and the Health, Education, and Welfare Department experiment is new. Educational interest has been excited about this whole opportunity. People got together and decided that they had to do something in this country, too. They have been thinking about it, but they have to do some experiments. The Department of Health, Education, and Welfare and the

Corporation of Public Broadcasting united in the last 6 or 7 months and made the proposal to NASA. As an experiment, NASA put a special package on an Applications Technology Satellite (ATS). They have not decided where the experiment is going to be performed, but the prospective areas are Alaska, the Rocky Mountains, and maybe the Appalachian part of the country. The Rocky Mountains seem to be an especially good site to conduct these experiments. There will be three components of this experiment: (1) there would be satellite educational television (ETV) transmissions of public programs to television stations, (2) there would be delivery of programs to cable-television head-ends, and (3) delivery of programs to schools by rooftop installations. The whole concept will be tested in the summer of 1973.

One of the major opportunities that is awaiting people is that sometime in 1975, they will put up an ATS-G satellite with very high power broadcasting capabilities. They have not decided at this time what the shape of the experiment will be; at this time, users are working to define their experiment, but no decision has been made regarding ATS-G, to date. So far, most of the interest has just been in the delivery of television and radio programs. Stanford University has been a pioneer; they have, for the first time, investigated the feasibility of delivery of computer-aided instruction to remote and isolated institutions. Professor Jamison did this in May 1971, and he is in the process of doing it again in the near future.

Transcribed from tape

# SPACE BENEFITS TO MANKIND AS SEEN FROM A FRENCH POINT OF VIEW

By Jean-Pierre M. Pujes
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Being an aerospace engineer, I feel deeply concerned about the attacks against space research coming from the general public; i.e., students and politicians, as well as the man in the street.

I would like to show what benefits space has already brought to mankind and those to come in the future.

I will choose the French space program, as an example.

## The French Space Program

In France, like in most other countries, the space program started as a military effort in the late fifties. At the beginning of the sixties, a complete series of rocket engines were available as a result of the first phase of the "Force de Frappe" (the French deterrent) development. But in 1962, though a certain number of rockets had been launched for scientific purposes, civilian space research had yet to be fully organized on a national basis.

The French Government then created the Centre National d'Etudes Spatiales; i.e., National Center for Space Studies (CNES), the French space agency. One of the first tasks of the CNES was to control the development of the French satellite launch-vehicle DIAMANT. From 1966 up to now, seven satellites have been launched by DIAMANT (six French satellites and a German one, DIAL). In addition, two French satellites were launched by U.S. Scout rockets as a result of a joint Franco-American program. The first DIAMANT-launched satellite was purely technological. The following ones were merely assigned to scientific research. However, the last French satellite, launched by a NASA Scout rocket from Wallops Island, Va., in August 1971, was already an applications satellite. This satellite is part of a multinational meteorological program, EOLE. According to this program a few hundred balloons have been launched by the French from Argentina. These balloons fly at a constant altitude and are pushed away by the winds. They are located and interrogated by the satellite to which they give the values of the temperature and pressure of the atmosphere around them. Then the satellite sends back that information to the nearest ground station. The interest of using a satellite is to know, simultaneously, the characteristics of the atmosphere at very distant points over deserts and oceans, where no meteorological stations exist on the ground.

From the positions of the balloons, meteorologists will derive the directions of the winds, and using the telemetered informations, should be able to predict the evolution of the numerical parameters of the atmosphere. This is important because, until now, the photographs taken by the former satellites gave only a qualitative and not a quantitative idea of the atmosphere.

This satellite is an example of what France intends to do in space during the coming years. The purely French national program will consist of only a few small satellites, either technological or scientific. Their number will be limited to the minimum necessary to maintain the high level of knowledge of the space industry and research laboratories. The most important efforts will be directed toward applications, and they will be made in cooperation with other countries either on a bilateral basis or through multinational organizations.

## International Cooperation

France is already involved in many international programs:

1. With Germany and Belgium, France is building a telecommunications satellite system, Symphonie.

2. The Russians are to launch a French

technology satellite before the end of the year; also they plan to use the Guiana equatorial launch site for some of their sounding rockets.

3. India, as well as Pakistan, is building French sounding rockets under license.

4. France is also one of the most affluent members of such European organizations as the European Launcher Development Organization (ELDO), which is building launch vehicles, and the European Space Research Organization (ESRO), which is making satellites.

5. Last but not least, France and the United States have cooperated since the beginning of space research on many projects, and the cooperation still continues. This cooperation is considered so important that France has a permanent representative in Washington, who is in charge of space problems. As far as scientific research is concerned, French scientific experiments will be flown on two American satellites, the Orbiting Solar Observatory (OSO-1) and the High Energy Astronomy Observatory (HEAO-B). On the other hand, U.S. sounding rockets are to be launched from the French Kerguelen Islands, close to the Antarctic. Furthermore, French scientists are studying lunar samples and they are, after Great Britain, the most important national group outside the United States to do so.

On applications programs, apart from the International Telecommunications Satellite Consortium, INTELSAT, France has an agreement with the United States regarding the ECOLE project mentioned above, and collaboration on a future data collection satellite. The Television Infrared Operational Satellite (TIROS-N) is on its way. The AeroSat systems project of air traffic control over the oceans, which was initially a French project in relation with the Concorde supersonic airplane, is now a joint U.S.-European program. MeteoSat is also a joint program, which was at the beginning a French-American meteorological project. Finally, France is looking forward to participating in the post-Apollo program (Space Shuttle and Station), if the conditions are acceptable. All this cooperation has proved useful, as it has considerably lowered, for each nation, the cost of space projects involved.

## Space Benefits to Mankind

Though the part of the French gross national product given to space activities is very small (less than 0.4 percent), the results achieved have been great.

Space research is no longer a way to gain prestige only for the French Government. Nor is it a means to improve technology in other fields of activity, except, perhaps, for some cases (participation in the post-Apollo Shuttle program might be justified by its consequence for the French aeronautical industry).

The direct benefits are by far the most important ones.

Scientific satellites help increase our knowledge of the universe. Astronomers can look at the stars from a satellite, for instance, without being hampered by atmospheric radiation absorption. Space astronomy is particularly important. Though some scientists do not accept the idea, it can be confessed that one of the reasons why space astronomy experiments are financed is that the results may help understand the process of energy being produced by nuclear fission. Such an energy production exists in stars, whereas on earth, the only way of producing nuclear fission energy is still the hydrogen bomb, which is not of a very convenient use.

Solar observation satellites are useful, too, since the sun is by far our most important source of energy and as the weather is dependent on solar activity. As a matter of fact, solar observation satellites are, in the long run, meteorological satellites. However, direct application satellites will soon bring benefits to mankind. Meteorological application satellites have proved useful saving many lives forecasting hurricanes. New developments, like EOLE, will help much more to accurately forecast the weather. Data collection systems, inspired by the EOLE technology, will authorize collection of data coming from very remote areas on the oceans as well as on earth. One can expect to get a better knowledge of the streams by replacing EOLE balloons, for instance, by buoys. This could be useful to the meteorologists, as well as to the oceanographers or the sailors.

Communication satellites are, of course, such a convenient solution to communication problems, particularly across the oceans, that within 20 years the cable industry will encounter a lot of difficulties if it does not react rapidly.

Navigation satellites will help programming aircraft landing and will save passengers time, permit better air traffic control and better communications between airports and airplanes, and increase the airlines' efficiency and help reduce the fares.

Satellites, at least, will help to obtain a better knowledge of earth resources through remote sensing. The United Nations is sponsoring an action on this subject. France has already done some preliminary work with aircraft and balloons, showing how much better results are when increasing the altitude from which observations are made. Until now, some forests in the south of France, for example, which were believed to be sound, proved to be completely infested. This fact would not have been easily known through conventional means.

## Conclusion

Space research has been very useful. Direct benefits have already proved very important and more are coming. In addition, space research has helped develop cooperation between nations, thus preparing a better world to live in.

# FORUM DISCUSSION

## SPACE PROGRAM BENEFITS AND THE PROBLEM OF TECHNOLOGY/USER LINKAGE

| | |
|---|---|
| MODERATOR: | Jesco von Puttkamer<br>President, HATS |
| PANELISTS: | Dr. Franco E. Fiorio<br>Italian Embassy, Washington, D.C.<br>Chairman, U.N. Working Group on Remote Sensing of the Earth |
| | Jean-Pierre M. Pujes<br>Scientific Attaché, Embassy of France<br>Washington, D.C. |
| | Dr. John Hanessian, Jr.<br>Director, International Studies Group<br>George Washington University |
| | Earl Hubbard<br>Special Advisor, Committee for the Future<br>Lakeville, Conn. |
| | William Hamilton<br>Manager, Space Shuttle Program<br>The Boeing Company, Seattle, Wash. |
| | Woodrow W. Diehl<br>Board of Directors, National Corn Growers Association<br>Des Moines, Iowa |
| | Dr. Krafft A. Ehricke<br>Chief Scientific Advisor<br>North American Rockwell Space Division |

## Jesco von Puttkamer

The forum discussion is intended to give the audience a good chance to ask all those questions which they may have developed in the course of this Conference, or in the course of this morning's session, to openly discuss certain points with the personalities exposed here to the public. Each of our panelists is going to speak about 5 to 10 min on his view with regards to, first, the general area of space applications or space benefits, and possibly also to those two major problems which we have unearthed in the last few days, and which were discussed here: The first problem is, who should be the one to provide the link, or who should be the linker between the quite complex technology area and the user side — Should it be the universities, the private citizens, or the government (in this case, NASA) who really should train, sponsor, control, and direct the linker? The second problem is that there are definitely some technology areas which seem too complex to be suitably related to the public, even by a good linker. These two problems were mentioned here and discussed, and maybe all of our panel speakers can address these points and offer their views.

## Franco E. Fiorio

I will start with a brief comment on space benefits. Space benefits are very difficult to assess. There are benefits flowing from many different parts of the space program. There are the direct benefits, such as communication systems, then the indirect benefits, such as for advanced technology, and some still more indirect benefits, like medical advances because of space research.

One of the most visible benefits, of course, is communication as we have it now. I am not referring to the future educational systems, which will provide tremendous benefits, but the benefits we have now in time and money, as a result of developing the global system. I remember 4 or 5 years ago, when I wanted to speak to Rome on the phone I had to wait about a couple of hours and spent about $10 a minute. Now the time is reduced to zero; I can just lift the phone and speak to Rome immediately, and the cost has gone down to $5 a minute and it will be $3 a minute starting January 1. It will go down to $1 a minute, and the final and ultimate aim of the high-power satellites of the future will probably be to be able to dial any place in the world with just a 50-cent coin. This is a tremendous benefit because it is communication within communication. The progress of mankind is linked to the possibility of communicating to others, the understanding with each other, and the only way to do it is to talk to each other, not to mention the advantage of the commercial and industrial nature of exchanging data and information and bargaining on an instant basis.

Now, the question of the link between the space experts and the public has been raised here. There are many links. The first link, speaking on an international basis, is between the space-developed or developing nations and the space-undeveloped ones; here the first step is to convince the leaders. If the leaders of the developing countries in the space realm are not convinced that space might offer some practical benefits, even of political if not economical nature, then nothing will happen in that country. That link is supplied by the United Nations bodies, both the Committee for Peaceful Use of Our Space and the Economic and Social Council. There are many bodies in the United Nations which are concerned with space, indirect and direct, and those are the ones who can convince the leaders, provided the action is properly coordinated.

As far as the link in each country is concerned, I would not take any position to say that it is the leading space agency's responsibility or the public's responsibility. But I believe that one of the most important roles to be played in that field is the role of the press — the technical press especially — to disseminate the information, to supply the public with the data, and to explain to the public what it is, in terms so that the public can understand. Of course, we have a built-in problem here. At this moment in the U.S., for instance, the technical press is dying for the lack of advertising, because of lack of money for the space program. It is a kind of vicious circle — the more the public is willing to support the program, the more money the government is willing to allocate. The more money is available to the industry for advertising, the more the press is able to break the bread of the information there is. The press and all information media, like television and radio, that is the real link — that is where the link is.

In closing, I would like to comment briefly on the earth resources satellites and the broadcasting problem. The situation of broadcasting is that discussions in the United Nations are temporarily halted because of the uncertainties that he mentioned about the programs. Although there is an easy solution in that the country which does not want to receive certain programs might prescribe certain specifications for their receivers — typical of a dictatorial type country — specifying what kind of a receiver with fixed frequency to be used. Those frequencies would then be the only ones that can receive anything. This would prevent them from receiving unwanted propaganda. Of course, even on a simple frequency there can be some jamming and overlapping that could not be avoided. In any case, in its last session the United Nations refused to reopen discussion of the broadcasting satellite working group, for reasons of these uncertainties. This decision was supported by the two major powers.

As far as the earth resources satellites are concerned, the field is completely open. The various problems that Dr. Hanessian mentioned are on our table. We have a Working Group that I have had the privilege of chairing, and it will meet in May 1972, probably one single meeting, to organize the work. There is a definite need to assess all the social, political, and technical implication of this brand-new area very carefully before proceeding with any kind of proposals. This view has been shared, practically, by all members of the group.

## Jean-Pierre M. Pujes

Earlier, in my paper, I presented an optimistic view of the matter of space benefits. As a forum is a place of discussion, I would now like to bring up some of the problems that we will be facing in that area. And I would like to illustrate them with some examples.

As we have a farmer here on the panel, I will relate something concerning agriculture, that happened in France recently. We had a discussion of how satellite surveys could be helpful to agriculture and ended up with an economical problem which appeared to be very difficult to solve. Some countries, like the U.S. or France, have an overproduction of agricultural products, such as corn, wheat, and the like. If we had a satellite which could tell the farmer about everything that is going to happen from a meteorological point of view, he could get long-range forecasts with which he could do a lot of things. He could have perfect crops and could — so it seems — become rich. That would happen in the long run — but I am not so sure that it would be as simple as that in the short term. With an overproduction, prices are low, and the government is obliged to pay the farmers to provide concessions to them. If the satellites could help getting better crops, we would get an even greater overproduction, and the prices would get lower and lower. Thus, while space surveys, in the long run, undoubtedly will be of great benefits to mankind, in the short run you really will have an agricultural problem — the problem of farmers having a lot of crops without knowing what to do with them. If we want to provide the farmers with a meteorological satellite, we will also have to make an economical plan to help the farmers during the first 2 or 3 years. It is not enough to deal with technological matters; we also have to deal with economics and economic problems.

The second example that I want to discuss is on political problems. We have, or had, a program in France where we wanted to use a Symphonie telecommunications satellite for education in Africa. In a large part of Africa the population either speaks French or has a knowledge of the French language. We intended to broadcast educational programs on Africa, but we ran into a political problem because each African country wants to have its own program. It is almost impossible since there are so many of them. You cannot have one satellite and 10 or 15 television broadcast channels; technology at the present is just not ready for this. So we had to drop the project, for the moment.

A third problem that we have to face is purely financial. In France, the budget for space, as I have said earlier, is about 0.36 percent of the gross national product, and it is going to stay at that level. If we intend to participate in a large international program, like the post-Apollo Program, for instance, we are faced with this problem: either we have a very small share of the program and it is not worthwhile to participate, or the program has to be limited. Any French participation, as the program is now viewed, would only be a few percent, 1 or 2 percent, perhaps not even that. We cannot increase the amount of money that we can give to this program, so the program has to get even smaller. One of the ways could be to lengthen the program and have the per-year amount of money spent become smaller. So this is a purely financial problem, and there are many of these problems in the political, economical and administrative areas. A lot of people will be needed to solve these problems, whereas most technical problems have been solved already or are going to be solved. For these reasons, people working with space have now to apply their capabilities, not to solve technical problems but to try to solve these kinds of problems. I really think that half of the NASA people would have to work on this problem if they really want it to be solved. The real problem is to convince the government that this is what has to be done. I do not know if it is possible.

## John Hanessian

We have problems! As you know, we have had many campus problems in the last few years. It seems this year that the students have other things to do. I might add, they are primarily worried about what job they are going to get when they finish. But more and more it seems that we have the same problem that the government of France has – money. Let me explain its relevance to the point in question. For a number of years, as you know, the Federal Government has provided a considerable amount of money in the form of scholarships, fellowships, or research grants, etc., to enable universities to develop and further their graduate careers particularly in science, engineering, and related fields. The government has played a very important role in this because universities just do not have the kind of money that is necessary to do this. At my university the tuition for 1 year is $ 2100. It costs us $4000 per year to educate each student that passes through our university. Where is the other $1900 coming from? Sometimes we ourselves do not know the answer to that. Last year we had a $95 million budget and ended up on June 30 with a $1473 surplus. We did not run a deficit, but we came that close to it. I do not know what is going to happen this year. With these kinds of financial problems, there is obviously limited money that we have available to give to students to do their graduate work. So we keep looking at the Federal Government for continued support.

Unfortunately, the Federal Government in the last few years has just gone in the opposite direction. They have reduced funds, withdrawn, and moved from education. It seems they are no longer interested in helping education per se. When we talk to the National Science Foundation or other agencies along the lines which are relevant here, we always get the same answer, "We do not have this kind of money for education anymore. We will only support the research that you do, and you have to prove to us that the research that you are doing is going to be of benefit to the U.S. Government and, more precisely, that it is going to benefit our agency." Well, that is a pretty tough problem. How can we do research, for example, that is going to benefit a particular division, within a particular bureau, within a particular agency? It has become very difficult. When we, for example, put on the kind of symposium where we bring together government people, university people and the public, it comes out of our own pockets; we have to pay for it.

This gets us back to a central question. If the universities are so worried about existing and about educating students, what can our role be in the future in this particular context of linking or otherwise standing between the government and public, or between the government and other sections of the informed public? I do not know. You can do very, very little without money, I can tell you that – and we do not have any money. Columbia University in the last 3 years has suffered a deficit of $ 40 million. They have got money now, but one of these days they are going to run out of money. We are already seeing things that we would have never imagined. There are universities that are actually closing their doors. They are going broke. One of the things that this government, and I mean this administration, has got to realize pretty soon, is that you cannot withdraw public support from universities and still expect them to pay their bills the way they have to these days.

The linking is a very difficult kind of problem, and I do feel that universities and university personnel can play an extremely important role. I have graduate students who want to do their graduate work on policy problems related to space; they want to work on some of the things that we have talked about here. We have to pay them a certain amount of money to keep them in the university, or they have to go out. They have to eat; they have to live. We do not have that kind of money anymore. The government has taken it away from us. We cannot bring students here to work on these kind of problems unless it is of particular relevance to a particular bureau of a particular agency.

I guess you might interpret what I am saying as a public appeal, but I am really talking to you as taxpayers. We can play a role, a very important role, and university people have one great advantage – they are objective. We are not government workers, we are taxpayers and we can play a role here in this game, between the public, the government, the technical and the international community. But without money, I am telling you we are going to do very, very little in the next 10 years.

## Earl Hubbard

We are in an age of "Why." You just heard the statement that professors have to eat. There is a story told about Frank Lloyd Wright, the famous architect. A young architect came to him and said that he could not do the pure, beautiful design he wanted to do because he had to eat. And Frank Lloyd Wright said "Why?" And that is what is being asked of you, on every level. This is an age of "Why."

There is a credibility gap dividing the people and the so-called technologists. This credibility gap exists on the question of "Why." The issue is not, what is the future of the space program? The issue is not, what is the future of this earth? The issue is, what is the future of mankind? That issue depends on mankind's awareness that he is now outgrowing this earth.

What links all peoples of this earth is the need for new worlds. The issue of cost which has been discussed here often is the issue of, can mankind afford to survive? The only cause on earth that needs people and the best that people have to give is the cause of the need for new worlds. All other causes deny the need for man. Consider the causes we have today. There is overpopulation; if you go to the people and say, "Join in that cause," you have to realize that they are the population you wish to control. If the cause is pollution and you go to the people of the world, you have to realize that they are the pollutants. There are too many of them for this world to sustain. If you go to the people of this world and say, "We need you for war control," you have to realize that in a world without a future, people would rather die fighting than die as a vegetable. And if you go to the people of this world and say, "Join us in fighting drug addiction," you have to realize that in a world without a future, man is not needed at all. Not to be needed is very painful — not to be needed for your capacity to conceive children, not to be needed for your capacity to work, not to be needed for your capacity to create is unbearable.

The issue that we are discussing here is the issue that all mankind must discuss. That issue is whether mankind desires to have a future or not. You here in NASA are building mankind's only hope for a future because you are building the only public stairway to the stars for all mankind. There has been discussion here about "international." We are one body. There is no "international" in this body. If we, as we approach 1976, declare the need for a new right, the right of mankind to have a future, we can invite the free world and all who would be free to join us in signing this declaration. Within this declaration there is the option of a new constitutional convention for a world nation dedicated to giving mankind a future. You people, mostly, are "How" people, and I expect you will work out how this can be done. But I think the first task is for you to start asking yourself, "What will happen if we stay on this earth?" Run this through your computers, because all that you are doing with your benefits for mankind is to accelerate growth, aspiration, and spiritual growth. You are, in other words, accelerating mankind's suicide unless you know and can tell all that you know that the need now is for new worlds.

## William Hamilton

I would like to address the first subject that the Chairman commented on, namely, the question of the link between the technical community and the public, or the technical community and the government. I believe there is a real need for communication and I agree with Dr. Fiorio that the real link is the media — the press, television, and radio, if you will — because that is the source of information that the public uses, and the public influences the government, especially in the U.S.

There is no question in my mind that space, thus far, has provided significant benefits for man. I think it will continue to provide more benefits for man. From the technical side, we know how to adapt satellites both near earth and farther out — technical explorations to benefit man. And we have done that with reasonably costly vehicles. I believe the next step is to devise means for doing those things for fewer dollars, or to do more for the same dollars. I am proud to be associated with the Shuttle Program and to be working with the NASA people on that, because I believe that is a step in that direction. It is aimed at reducing the cost of putting payloads in orbit by a factor of 10, and I think that is worthwhile. We do need easier and more economical access to space, and I believe when we do get that, there will be many more improvements that will come to mankind, both for the whole world and this nation, the U.S.

I am thinking of many of the developments that we just do not see today. As individuals, as humans, and especially as the technical community, which many of us here are from, we are usually a little optimistic in the short term and very pessimistic in the long term. We do not have the vision to see what is over the horizon. One of the developments, for example, that I have been involved in, has been the jet transport. In 1951, 20 years ago, when such studies were made by the Boeing Company and by the Douglas Company, most of the experts in the country said that jet transports were impractical; they had insufficient range, insufficient payload, and they were too costly to operate and too dangerous. Many noble and conscientious people made very moving speeches on this subject, and they could prove to you mathematically that there was no sense in working on that. They said that in 1970, even if it were practical, there would only be a market for 100 to 200 jet aircraft, at the most. In 1971, the 707, DC-8, and 747 all have ranges in excess of 6000 mi, and the cost to transport a passenger has dropped to between one-half and two-thirds of what it was with the DC-7 type aircraft at that time, even though the employees of the airlines are paid more than twice as much per hour, on the average. As far as the market is concerned, the Boeing Company sold over 2000 jet transports and the Douglas Company sold over 1000 jet transports, and there will be more sold because they are an economical and efficient means of transportation.

The dollars spent in the space effort, I believe, will bring forth benefits and growth, additional capability to the country and to the people, that we cannot envision at this moment. Of all the dollars that we spend in the space program, the vast majority are spent in the U.S. They go for wages and salaries, just as the money spent in anything else in the economy. In addition, they do provide direct benefit for mankind, and they do provide the knowledge on which to build the future, from a scientific and industrial standpoint. They also improve our position in the community of states in the world, both from a prestige and a technical standpoint.

There has been a lot of talk about the value of international cooperation. Cooperation is a desirable thing; however, I think there is a real value in competition, and if you have no competition, things tend to stagnate. The comment made by one Russian scientist to this effect is probably reasonably true, being that if there was one world space program with all nations participating in it, there would be, in the long run, far less space exploration than if there was a competition between nations to achieve or to outachieve the other side.

## Woodrow W. Diehl

The first thought that comes to me is, do you remember a few years ago when Governor Romney went to Saigon and when he came home, made the statement, "I guess they brainwashed me"? Well, I am certain that I have been brainwashed here in the last few days, because you people certainly have sold me on space. I am so fully convinced of this, that it seems that practically every answer to all our problems is going to be provided by the space program. Pollution . . . you name it! Perhaps, someday we could have heaven on earth. Of course there is one thing that is bothering me a little bit at my age. I would like to have you fellows hurry a little faster, because I sure would like to enjoy a little heaven.

A number of times I have been a little embarrassed, with all you gentlemen here. As we look at the name cards, you say, "Who are you?" Well, I am an Iowa farmer. Then, I say, "What are you? Who are you? What do you do?" And before I know it, the pedigree gets longer and longer and I wind up with what I call a dumb farmer complex. So I have decided to do something. Most of you have your calling card or name card. Well, I have never carried a calling card or name card in my life. Lo and behold, that is one thing that a farmer does not need. After he has been on the farm and goes into town, there is no problem in knowing who he is. But maybe I will be invited to something like this again, and I am going to have a calling card. When someone asks me, "What do you do?" I am going to tell them that I am the chairman of the board and executive officer of a corporation. If they press me a little further, I am going to say, "Well, we have a Cattle Feeding Division, a Cow-Calf Division, and a sizable Hog Division, and then we have an overall General Farming Division that produces all the food and roughage for these animals." But here is what has got me worried. If they press me any farther, well, then I will just have to tell them that I am an old Iowa farmer.

Last week I was in Washington, to appear before a Senate subcommittee in support of a strategic grain reserve bill. Maybe I should back up a little bit. A year ago everyone heard of the corn blight. But did you know that we had raised enough corn for everyone, that there was no shortage, and that we still had plenty of corn left over? There was a lot of concern about the blight, so this spring — before planting time — the Department of Agriculture and those that are supposed to know, decided to play it safe about the blight and told us that we should plant a little more corn. Do you know what happened? We raised a billion bushels more than we needed — 1 billion bushels! For domestic use and export it takes about 4.6 billion, and we produced over 5.5 billion bushels! And the price has dropped; everyone is talking about having no money — well, here comes my pitch. Corn was $1.35 to $1.45 all last year. Now it is down to 93 to 95 cents a bushel, and they tell me it cost $1 a bushel to raise it. With the crop we had a year ago, the net return will be many, many times more than our crop this year of an extra billion bushels. So that was why some of us went to Washington to see if we could not get this bill through, whereby the government would establish this strategic reserve and take a few hundred million bushels for this reserve off the market and off our hands, and then maybe we could get a $1.10 a bushel for the rest of it. There were four or five Senators of the subcommittee group sitting around the table, listening. As the day went on, one was gone, another was gone, and toward the evening when the turn came for me to get up and speak my piece, one Senator sat there, and he was nodding. I do not think that we are going to get anywhere! So we are all in the same boat, are we not?

There is one thing, one thought that I would like to make. We all go around tooting our horns and trying to promote what we believe in, but about 0.9 of our tooting is among ourselves. The right people do not hear, and it seems in this modern, fast living society everyone of us finds himself in the minority. I do not know any other way out. We had better start listening to one another's problems and paying attention and start helping one another.

I have thought a thousand times in the last week that I have spent here, "If I just had a thousand farmers that could sit in and listen in on this!" All this information, it is fantastic! I cannot even scratch the surface and try to distribute this. I am going to do all I can but it takes a lot of people and a lot of doing. When I get home, you know what I am going to do? When I get home, I am going to go out and walk around my cattle and hogs and my boys and I am going to tell them this, "Do you know where I was last week?" No. Then I will tell them — when I talk my chest is going to get bigger and bigger and the buttons are going to fly — that I was down in Huntsville and rubbed shoulders with the smartest men in all the world, because they were the ones that put man on the moon — the greatest thing that has ever happened. I am mighty proud to have been here with you fellows.

## Krafft A. Ehricke

One thing that struck me in listening to a number of talks and also in listening to a number of comments I have heard here today on the panel is how much emphasis is put on near-earth, and how much it is taken for granted that the things that we can do in near-earth space — resources satellites, communication satellites, and so forth — are good for mankind. At the same time, I am thinking back to the large budget battles that we presently have to fight to get people to accept the nonrelevance of a probe to Mars, to Jupiter, or the continuation of the lunar program. I have to think back about 20 years ago when I heard these same stories that I am hearing now about lunar or planetary operations. When I hear these stories about near-earth operations, it occurs to me how well have we actually sold space. We have sold it so well that everybody is getting stuck in near-earth space and does not recognize that this whole spaceflight is one integrated complex, that you can not have utilization without exploration, and that the very arguments that are today very often used in order to put down an Apollo mission or in order to put down our beautiful flight of Mariner IX to Mars, have been used 20 years ago with respect to near-earth space. I was actively involved at that time and I also got some arguments which I am ashamed to repeat, because they were so stupid. Or let us say, at least they were lacking any foresight or imagination. That underlines also the fact that looking a little bit ahead, beyond what is immediately necessary, is paying off in a great way. Ever since the Renaissance, Western civilization has done it. We do want to exploit the opportunities that near-earth space gives us, but we have got to keep also the long-range oscillations in mind that affect our progress beyond this.

Right now we are fighting for the Shuttle in order to exploit near-earth space better, to explore distant-earth space also more economically, and to accelerate the process of returns on the investment a little bit better. All this is part of science and technology, a creative activity, which should be part of our civilization. It is amazing to find in a civilization, that is techno-scientifically oriented to the core, such a negative reaction to science and technology and such a shallowness in the face of past human experiences, such as some of the remedies that are offered by those people who believe that we can get along very well with a secondhand future, returning to an outworn past.

That reminds me of a little story about a businessman who used to travel regularly by airplane from

New York to California on business. But when bomb explosions in airplanes increased in number, he stopped flying and took the train. He explained to his business partner that he did not dare ride planes anymore because there was just too high a probability — something like 1 in 1000 or 1 in 500 that there might be a bomb aboard, and he did not want to take that risk. But one day he came flying in again by plane and his business partner said to him, "How come you are flying in by plane?" "Well," he said. "Look, the probability that one bomb is onboard a plane is about 1 to 500 or 1 to 1000, but the probability that there are two bombs onboard is of the order of 1 in 1 million. Ever since that time I carry a bomb in my suitcase, you see." That is about the logic of some of the remedies that we are getting these days. So we have to keep in mind that we have to recognize the short-range as well as the long-range situation.

The extraterrestrial imperative has two major objectives. One, and the main one, is the maintenance and continuance of human civilization. We had 5000 centuries of culture, in which the cunning, effective, efficient, and ruthless beast that preserved itself against nature emerged, and about 50 centuries of civilization in which we are now starting to selectively promote some characteristics and suppress others. The momentum of 5000 centuries cannot be wiped out by 50 centuries; it is too much. We need thousands of years of civilization. We cannot have it with a mankind that has cosmic powers but is sentenced to solitary confinement on one planet. It is just not possible, and it is not reasonable. The second, equally important factor is the restoration of equilibrium between this life form operating on information metabolism, and a planet whose biosphere is not geared to take into account the effects of information metabolism, of tremendous industrialization, and of tremendous processing of energy and matter any more than earth Number One was capable of caring for life on a planetogenic basis. It took the chlorophyll molecule development for life to broaden its basis and include a cosmic resource, namely, the sun, and thereby, put that particular life on a permanent basis on this planet. Just as the chlorophyll molecule is the center and the motor of the biosphere, so the brain is the center and the motor of the androsphere — a new and dynamic equilibrium-type sphere of activity that encompasses many environments. In between the chlorophyll molecule and the human brain, everything else is basically transition, for the reasons that I pointed out in my earlier talk, namely, submission to existing conditions . . . , which is impossible for man to do. This may be his cross or his crown, whichever way you want to look at it.

The basic aspect of the extraterrestrial imperative is astro-ecology and geo-ecology. The astro-ecological promises are the broadening of mankind's resource base, the development of advanced technologies in the service of mankind, free of biospheric constraints and free of social implications and complications which we are encountering increasingly, because man no longer can be forced into a still-closer living together with technology, and because technology disrupts the longer term need of man for time — the grace period that he needs to evolve as a civilized being. This is the humanization of man in contrast to the homonization of man — where he develops the maturity, the social structures, and all the other attributes — moral and ethic — that make him the higher ethical being that he dreams of being. The present pressure of survival that requires an ever more stringent technology is interfering with this development. For this reason the despair of many people, also of many environmentalists and of many of those that try to listen to the subtler and longer-range frequencies of human development, is understandable. What they do not know is that shaking off the technology and — in other words — backing off into a secondhand future, is not the solution, but breaking through the bottleneck into the greater future is the clear answer. Astro-ecology also provides us with the possibility and the option of separating geo-incompatible production processes from earth. These are the types of processes that cannot be properly integrated as such into the biosphere and into the great physical, chemical, and biological cycles of earth. The separation of production and consumption is the core requirement for the maintenance of human civilization, because we cannot maintain human civilization without human consumption, which means living standards. We cannot have consumption without production. We cannot have production without pollution — without gradually expanding into space with our productive facilities. This is a process that will take on the order of 100 yr, but it begins with a number of near-term goals. From this umbrella-type, metagoal specification, we can now work backward into specific goals. In other words, we are now like a man in New York who has at last made up his mind whether he is going to Miami and therefore should map his first step out to Atlantic City, or if he goes to Los Angeles and therefore maybe he should map his first step in the direction of Buffalo.

Geo-ecologically, the exterrestrial imperative promises the integration of geo-compatible industrial processes into the terrestrial cycles, as mentioned before. This is a benign industrial revolution, minimizing pollutive and biocidal side effects and requiring global management, which is not possible without the extensive use of satellites and space stations. Out of this arises the great new opportunity for environmental specifications and environmental compatibility for doing those things that need to be done to sustain human civilization in those environments where they are least interfering, least interceding, and least pollutive. A pile of cow dung on the moon is typical of a pollutant, not a nuclear detonation. A nuclear detonation on earth is typical of a pollutant. And a pile of cow dung is not typical of a pollutant on earth. You have specialized environments and you have things that you do with minimum environmental interference in mind. The environmental compatibility principle, thus, is a very important factor in sustaining human civilization.

The geo-ecological component aims basically at an integration to the extent in which man's activities continue to go on here on earth — an integration between the biosphere and the more cyborgian civilization of man, the techno-scientific civilization. In other words, you create a gigantic geo-cyborg whose brain ganglia, in part, would be our communication satellites, while the big eyes that are needed for this kind of geo-cyborg would be the surveillance satellite, the resources satellite, and all the remote sensor satellites. Here is the immediate tie-in in near-term, practical connections.

Communication is also important from the standpoint of education. I was very impressed by what was said by many speakers here, to the effect that education is so vitally important because communication is a dangerous thing if it is the wrong communication or if it is wrongly understood communication, ever since Marconi somewhat simplistically tied the capability of communicating together with betterment of the world. But it did not happen. We had war after war. We had envy, hatred, misunderstandings, and discriminations as never before in the history of the world. If the tremendous communication explosion that will come to us in the next 10 or 15 years is not accompanied by an equally vigorous educational explosion, we may have a repetition of these things all over again. This is especially true since in the developing countries the knowledge of what represents healthy, good, and safe life will become evermore apparent as communication goes on. At the same time, if we cannot tell them how they can participate in it — how they can participate in a global development program that will not destroy all of us because it overloads this planet — then we will have again an outbreak of hatred, envy, and misunderstanding.

Another very important factor of communication is telemanipulation; it is not the possibility of transferring yourself through a radiation beam or electrical current, like Captain Kirk in "Star Trek" (this would be beautiful but it has its problems). Rather it is the capability of transmitting your dexterity. Imagine that people down here have a job in a factory in space, not because that space factory is run by robots (which it would not be) but it would be run by teleoperators, telemanipulated teleoperators — people whose dexterity here is being transmitted by light velocity into the factory in space or into the particular process in orbit or even on the moon. If you go farther out, the communication distance begins to cause a problem. Telemanipulation will also play an important role here on earth. Ultimately, it will be possible for a surgeon who sits somewhere in a hospital, with the aid of laser holographs, through communication satellites, and with the aid of a teleoperator at the destination point (say, a ship or some isolated island) to conduct — by remote control — a surgical operation, by having the body in three dimensions on his operating table and carrying out everything that needs to be done, as if the body were there. His dexterity is transmitted through the teleoperator. So, through satellites, we have the possibility of man's dexterity to reach out. We have possibilities to apply this to many industrial processes, thereby cutting down on pollution and thereby allowing the more isolated and autonomous systems within the environment, where we have them autonomous not because — as in space — the environment is hostile, but because the environment is so beautiful and must not be spoiled. These are some fantastic possibilities of communication of which the normal context of our communications satellite systems is merely the beginning.

Fundamentally, the space program is in the same boat as the developing countries. There is a demand for benefits just as in the developing countries; there is a demand for better agricultural means, for industrialization. But there is no capital; there is either the unwillingness or the incapability of providing capital. You see, we have a vast amount of capital in a country like the U.S. on any European country which is being reinvested all the time. The bootstrap operation suffers from the fact that the service needs that grow to the developing countries cannot be compensated to the extent required. That is the reason for the massive global aid. I feel that the space program must be a part of the global development program, pure and simple — a part of the global development program to which the nations of the world contribute. There is no question that the highly industrialized nations have to contribute a greater share than the others, because that is where most of the knowledge and most of the capital lies. But in contributing to these things they perform a form of foreign aid, of an astronautical Marshall plan which, I believe, is far more efficient than the old type of Marshall plan, because it encourages the advanced elements in those countries. It encourages the countries' capability of self-improvement and of progressing and thereby increases the share that these countries will be able to contribute.

We need a critical mass of the space program. With this I mean enough capital to make this program socially, economically, and ecologically critically relevant. You cannot do that with $2 billion; we have to have a bigger space program because space is relevant, no less than to the extent of the continuation of the human civilization.

## Open Discussion

Jesco von Puttkamer: The floor is now open for questions from the audience.

Jack Hartsfield: Dr. Ehricke, you mentioned the need for a bigger space program. Do you foresee or would you care to make any predictions on how long it might be before the space program could get back to a $5 billion level?

Krafft Ehricke: Let me give you a practical or a pragmatic or empirical answer. I think it is going to be directly proportional to the amount of pressure that an enlighted public exerts on Congress. You have, very clearly, in Congress the feeling that you can cut on the space program, and not only will you not get any political backlash from it, but also you will get the hearty endorsement of all those pessimistic people and doomsday prophets who say, "Well, we have already done too much in space." The Congressman reads the Harris Poll which asks the question in the following impossible way, "What is more important, rebuilding our cities or exploring Mars?" The answer is obvious. I finish all my talks by telling people, "The best thing that you can do for spaceflight is write to your Congressman and say that you heartily and totally disagree with further cutting the space program. In fact, you demand an increase of the space program." I wonder, for example, if it could help us to get a little bit closer to one particular Senator. I am sure we would have a very great advantage. There are Senators who really, honestly believe that the space program and the whole technology that goes with it is totally irrelevant or partially irrelevant. It depends exactly on the support by the public by writing to Congress, since that is the only type of communication that counts. Every time there is a real wave of letters, you get a change in Congress. This, I think, and an increasingly large and liberal education of the general public and communication between the public and us are the two things that will accelerate it. How fast it goes or how fast we will be back to a bigger budget will depend on the success with which these two things are carried out. But the pressure of the illogic of the direction in which we are moving will presently become quite apparent in the next few years. I am sure by 1980 we will have a much bigger space program, but by that time it may be too late. So I do not know when the earliest time is, it is unpredictable at this time.

Donald J. Frederick: One of the speakers brought up a very dramatic point, namely, that space can provide information on earth resources that will enable the corn producers to take care of such things as knowing where corn blight is going to be and thereby anticipating and winding up producing a billion bushels of corn more than what is going to be utilized in this country and in export. But at the same time, it is also known, that there are hundreds of thousands or even millions of people starving in various countries. So it seems that we have the problem of distribution of the benefits of space to certain segments of mankind that are not receiving them. Do you foresee any way in which these benefits of space might be more adequately distributed to the segments which really need them?

W. W. Diehl: I will give you a thought or two of my own on this. Few people have any idea of the tremendous productive capacity of the American farmer. Yet, we cannot feed the world and we cannot distribute all this wealth. We have the wealth, for example — this billion bushel corn crop that I mentioned, and we know that there are people that can use it. We are mighty big, but we cannot do that. The thing that we have got to do and can do is to give them education, technology, and the know-how. To me that is the only answer for the starving people of the world. I was on the National Food and

Fiber Commission back in 1966, and we studied all these things. There was a general thinking at that time that it would be just a matter of time, a few years, that it would be a problem to raise enough food. I think that I am farther out on this than most everyone else, but there are enough resources here in this world to feed all the people that are going to be here even if the population explosion continues, which I do not think it will, if we just can pass the technology on and teach them how. I have often thought that there are only two reasons for people to starve to death, as far as I can see, and that is ignorance and poverty. But that is like the chicken and the egg, I do not know which comes first. So it is a matter of education and of passing this technology on.

F. E. Fiorio: I have some pertinent observations to the same question which stem from the fact that last week I was in Rome discussing exactly this matter with the director for Agriculture Activities in the Food and Agriculture Organization of the United Nations (FAO), which has its headquarters in Rome. We from the Space Committee of the United Nations, 2 years ago, demanded of the FAO to get interested in and examine the program of utilizing remote sensing for general planning. The problem of having a billion bushels in the United States and 10 billion bushels of deficit in Africa or somewhere else is a global problem. It has to be approached from a global point of view, and that is exactly what the FAO has been created for. They are now working on conventional systems, that is, ground surveys. They recently graduated on airplane services in order to know where the crops are, how the crops are growing, and so on. But it is just in the embryonic stage now. However, they are beginning to realize that space techniques — like remote sensing in the agriculture field, which has been pioneered by Purdue University, incidentally — could be a great help. The other thing is that they are still groping around to see how it can be done. Tomorrow there might be a possibility by which these techniques can be developed; in general, the development is much faster than anticipated. You are planning for 10 years hence, and then you are finding out all of a sudden 5 years later that things are moving much faster than expected. It might be that there will be a global planning, and this type of problem of excess production in one place and less production in another will be corrected by rational planning. Incidentally, coming back to the corn blight: NASA ran a project of looking at the corn blight, and recently I saw pictures of corn-blighted crops and unblighted crops. If the techniques had been as it could be in the future, the problem of raising an extra billion bushel of crop would not exist because it could have been found out rather quickly that the blight was not so severe as expected. Thus, it was just a matter of interpretation and of timely communication to the farmers. Therefore, I believe that these problems, highlighted by Mr. Pujes and Mr. Diehl, are just growing pains and that they probably can be solved in the future by more rational utilization of space techniques.

John Hanessian: I want to respond to a point that Krafft Ehricke made. You have always taken it as an article of faith that space programs are worthwhile, that they are good and should be funded and supported. I would like to put this to you: I do not think that you people have convinced the American public of this. What I want to suggest is this: You said very truthfully that until there is public support and public pressure on Congress, you are not going to get back a $5 billion space budget. I would put it in a different way. You have to show the public that they should do that, and I do not think that you have convinced them yet. Going to the moon and spending $25 billion is not the only thing that you should have been going this past 10 years in terms of convincing the public that space support is a good thing. When it comes to this whole area of technology transfer and technology utilization, what do the people hear? They hear about Teflon, new brassieres that have been invented, and so forth. I suggest that this is not enough. The only thing that I see which is directly relevant and pressing home on the consumer that space is doing something for him, is when I see a television broadcast and at the bottom of the screen it says "Relayed by Satellite." That means something to him, he knows that certain program is coming to him because of a satellite; otherwise he would not get it. What I am saying is, until you intrude on his everyday life and show him that space is meaningful to him, you are not going to get him to write letters to his Congressman.

Krafft Ehricke: Let me add another 30 sec to this. I could not agree more! You are discussing this problem with one who has represented that line of thought. The official line of NASA is, of course, by necessity somewhat different because the programs are set by the government. And for the individual to bring out a somewhat broader aspect it is very difficult, especially in view of the fact that those people that are taking the emotionally more pleasing solutions in the population and antitechnology areas and so forth are actually automatically getting much greater coverage with television and the media than anybody else. If you would see my publications all the way back into the fifties, I have emphasized that it is necessary to answer the question, "What is in that for me?" I have long ago proposed that we actually make the statement, "Space is a business of experts but the affair of all people," a kind of slogan. It has not been done. I was appalled by some of the statements regarding man's flight to Mars that were made on the occasion of Apollo XI, rather than certain other things to be said. I agree with you 100 percent. I think that the total space community here has to turn around a little bit and give more emphasis to things that are important to people.

Jai P. Singh: I am a part of the space program but, I think, there is no doubt that the space program has many segments in it. It all depends on which one you put emphasis. Maybe in the past we have emphasized only one great part of it and we have not been showing to the public other things that are involved in it. These are certain things which have overshadowed some of the other important things that could be delivered to the society as such. I think this separation about the space program is correct. Maybe what we have to do at this stage is to take a hard look at the past to see why this backlash has been produced. We have not talked about this backlash – this antitechnology that Dr. Ehricke called backlash. I do not think it is an antitechnology backlash; I think it is a backlash for social direction in the technology – what is relevant and what is irrelevant and how you tie that relevancy to people. I do not think there is anything that you can call The space program. It has parts in it. You just cannot ask for a blanket assignment of money for The space program. You have to justify each and every segment to the people.

Unidentified Participant from Floor: I have a question for Mr. Hubbard. I did not see any hope in your argument that man is the problem in pollution, and that man is the problem in all these other issues that we are talking about. Yet, is it not the same man that is the problem in conceptualizing this idea of what the future is? So we are back to the same sort of basic element and problem. It seems to me that you just moved the discussion out of the specifics of pollution, drugs, war, and these sorts of things, into a more abstract or more general discussion. I wonder if you would elaborate on that.

Earl Hubbard: The argument that I gave this morning was as abstract as survival. We are outgrowing this earth. Every problem we have has one common characteristic: Growth – population size, pollution, drug, war, all of these. Therefore, in terms of survival, man has only one choice – new worlds. To reject this is to accept on this earth dictatorship, devolution, and death. In a closed system without a future, the only way to monitor the resources of this earth would be with total control. If you go to the people of this earth and ask them to comply voluntarily, you have to trade for their self-restraint a future. If you have no future to trade, you have to impose your restraints. The means of imposition would be a dictatorship, and the method would be devolution. Because no police force could hope to do it, you would put tranquilizers and sterilization chemicals into the water system; you would carry pacification programs over your communication. If you do not choose to go to new worlds, you have only one choice, that is, to maintain a dying species on a dying planet. That is how abstract my argument was this morning.

In terms of the value of man, you are right. We are moving into an age which will be basically theological, because the issue is whether you can think of man as a constant or whether you think he is a part of an evolving purpose. That issue, I think, is going to be where the battle is fought. But I was attempting here to deal with what is called pragmatics. Certainly, one of the major problems that you face is in the very title "Space Program." Nobody wants to put money into space. But if you go to people and say, "Do you want to buy a new world?" you can tell them that they will get the greatest bargain ever, as Dr. Ehricke has said – they can get two new worlds for the price of one, and that is the only way they will get either one. In learning to live on the moon and taking on that challenge, you are saying that you need everyone. You need new political concepts, new economic concepts, new methods of manufacturing, and the kind of manufacturing that is evolutionary is the kind that needs people, because on this earth, only people can do what has never been done before. With cybernation and automation there is a declining need for man to do the repetitive act. Therefore, there is a declining need for man, period.

If we take on this challenge of new worlds, we will have the motivation for self-restraint on this earth to clean it up. Why? Because we have to be the healthiest possible race. As it is now, there is no possible reason for this. You get up every morning, do pushups, eat fresh fruit and cereals, and at some point it is going to cross your mind, "Why be healthy?" That is precisely what is crossing the minds of the youth in this nation. The only answer that we have for them in our educational system is, "Because we are attempting to produce a consumer." In a world with too many people, that answer is not good enough; it has never been good enough. And one thing that is running through this conference is the estimation of man as a consumer. He is not! He is more than that!

George von Pragenau: I would like to ask Dr. Hanessian, is there not a certain development going on in the human race? We have farmers, engineers, and scientists who are heavily engaged in feeling nature, in talking to nature, not in words, but in feeling it. Then there is another group which are the talkers: the lawyers and the philosophers. I wonder, is there not a communication gap between the ones who feel the nature, the ones who have the urge to go to other worlds, and the ones who seem to be slower on the uptake or do not completely understand this urgent human need, this basic human need, and interpret it wrongly as consumer needs, for example, that we have to sell space? Do you sense something like this on the campuses?

John Hanessian: We do have a growing movement on the part of the students to make education "relevant." You know, there was a time when universities were called Ivory Towers. You had professors and a few administrators; now we have too many. The whole idea was to think, to write, to teach, and the point was that you could best do this outside the context of the environment around you. In other words, you had to withdraw a little bit, so that you could think and cogitate about it and teach. The students are rejecting this today. They are saying, "We do not want you to teach us only the science of politics. We want you to show us how you can dump Nixon, Johnson, or whoever." That is a very direct, relevant purpose. Now we tell them, "We cannot tell you how to dump Nixon or dump Johnson, but we try to show you not only the abstract, the philosophical, the theoretical approach in politics, but we are now going to start talking to you about the real world, a little bit about what really makes politics tick. After we show you a little bit of that, then if you want to go out and dump Johnson or elect Johnson, that is your business." But the biggest problem that we have is that so very few of our political science professors, in this particular context, have actually been out there working in this kind of thing. They go to school, they go to graduate school, they teach, they really do not know what it takes to dump Johnson or Nixon. Because of the pressure from the students, more and more of us are getting out into the real world. I think that if more professors had one foot out there and one foot in here, so to speak, we would be better teachers, and we would better perform the tasks the students want us to do.

A couple of days ago, I had lunch with a friend of mine in the State Department. He is in the Bureau of International Organization Affairs, and it was just one of those crazy coincidences — his various fields of activity happen to parallel mine. He is an international lawyer, works on outer-space affairs, on sea-bed affairs, and so on. We were talking, "Would it not be nice if we could switch jobs for a couple of years?" We started to think about this. It turned out that he could teach all the classes that I teach, and it just so happened that I had been working in areas that were very relevant to his job there. So we thought, "What would be involved? What would be the problem?" I said, "Well, all that I have to do is take a 2-year leave of absence. What do you have to do?" He thought about it and answered, "Well, the first thing that we have to do is get you a security clearance!" You can see the kinds of problems. It is not that easy to transfer and link and go across. Fortunately, I am in Washington; our offices are four blocks apart and we can get together and have lunch. To the extent that that linkage is worthwhile in your context, fine! But I do not know how this is going to help my colleagues in St. Louis, Iowa, or elsewhere.

Unidentified Participant from Floor: I am wondering if maybe the wrong people are selling the program? I wonder if anyone on the panel would like to make a comment about this. You know, that since we are in the program we are selling from the inside out. We are trying to sell the public on it, but we are the poorest people in the world to sell something like that. Is it necessary to create a religion out of it, hire an advertising agency, or do something like that to sell it?

William Hamilton: I agree with you, there is a real problem. I have attended many technical meetings where a lot of people got together and they told each other the same story, the same facts, and they cannot understand why the rest of the world does not understand. The real problem is communication with the public, the voting public, the large element of the public, I believe. I think it does take a dedication of effort and the realization that an important part of any program is to communicate the value of the program to those people who control the money, the budget, the Congress, what have you — but basically, it is the public. It has to be sold, and I think a major part of the effort or a significant part has to be devoted to that, with smart people trained in that area.

Ruth von Saurma: Are we not maybe ignoring how much the consumer is willing to buy of what we are trying to sell? The need of the consumer, I mean. Do we overestimate the need of the consumer, maybe, in trying to sell too much?

John Hanessian: Well, you know, it is sort of a "Chicken and Egg." Do you create a new need and then inform the consumer that he has a new need? That is what people did when they invented electric toothbrushes. I did not know that I needed an electric toothbrush until they invented it. I still do not have one. Or, this is the point that I really want to make, do you do something with the space program that the consumers already realize that they need, and bring that to their attention? I would say the latter. Do not create an artificial need, I mean. You know, Teflon frying pans are very nice, but we did lots of good cooking before without them. I am sure that the new brassieres are very fine, but the ladies were perfectly fine before. Hit something that they really need, such as this business with corn blight and so on! If you can show a farmer in Iowa that the space satellite up there is going to help him plant his crops better next year — I mean, really show him and demonstrate — he will write to his Congressman. You do not have to worry about him. But do not, for heavens sake, go to that farmer in Iowa and suddenly tell him he needs a new kind of Teflon frying pan that is only going to be given to him by aerospace technology. I just do not think that is going to work.

Al Reisz: I have a question for Mr. Diehl concerning the overproduction of corn and the use of satellites. I was wondering, since the planting season for corn, soybeans, and so forth is mostly sometime in April to late June, if it would be possible, by using the satellite, for farmers to know what corn or how much corn has been planted? As you mentioned, this year, for example, we had an overproduction of corn and its price is down to about $1 a bushel, whereas beans are up to $3, over $3 a bushel. We had too much corn planted but a lot of farmers were waiting to see how much was going to be planted. Well, could they tell, say by data from satellites? Could you get this information? Also, the late planters, they would know that too much corn had been planted and would switch to beans, would they not?

W. W. Diehl: Now you are getting into remarks that I should have made in my 10-min talk. Well, I am perhaps the only farmer here. I am over 30 mi away from home, so you know what I am — an expert I was hoping that someone would ask me to explain the farm problem in layman's language. Now you are getting into that area, you see, but we would have to continue this Congress for another 5 days to go into this and to lay out the farm problem to someone who does not quite understand. The basic thing is that agriculture is unique in this way; namely, the more efficient we get the poorer we get. I am trying to say that in industry they produce exactly what they think they can sell. They can guess it very close, and then they put a price on it. But you cannot turn 2 million farmers loose, without any overall supervision, and do that. So there is only one answer to the farmer's problem and that is, controlled production. Now the big question and the big problem is, how do you control production? That has been the argument through the years.

Al Reisz: If you planted too much corn and not enough beans, could you not get this information and plant more beans than corn in the late season?

W. W. Diehl: As an individual farmer?

Al Reisz: Yes.

W. W. Diehl: No.

F. I. Ordway: Can you predict the crop early in the season, after you planted it? This may be part of the question.

W. W. Diehl: No.

F. I. Ordway: You cannot predict how much of a crop you are going to get that early?

W. W. Diehl: No.

F. I. Ordway: So there is no predictive value, whereas General Electric predicts how many light bu they are going to put out.

W. W. Diehl: Let me elaborate on that. General Electric, when they build the light bulb, probably know right down to a hundredth of a cent what that light bulb costs, too, do they not? They know how many they are going to build, by a survey and their records of how many they sold before. When I plant my corn, I do not have any idea of whether it is going to cost me $.50 or $1.50 a bushel to raise that corn, until it is raised and in the bin.

Jesco von Puttkamer: I think what we are pursuing here is that we have 2.5 million farmers, 2.5 million individuals, each one planting their corn at their own good time. And now the satellite provides a possibility for those 2.5 million farmers, assuming that you can get them all under one hat, to take a look at those pictures and find out what their neighbors are doing and at what times.

W. W. Diehl: We do it all at the same time. It is estimated that somewhere around 1.5 million farmers raise corn. Well, I look at the picture; we all have the same information. I see in the picture that we are going to have too much corn, so I plant beans. If you were looking at the same picture and you were a farmer, you would do the same thing, would you not? What would we wind up with?

Unidentified Participant from Floor: I have lived a couple of years on the farm, and I think what we have here is a discussion related to dollars. Your whole Congress relates to the good of mankind. But the availability of food and dollars are not necessarily related, because you have starving people by the millions and you have an excess of food in one country. That really means that you do not have too much food from a mankind viewpoint, but you would not make any money for that farmer if he sold it or gave it away. So what we are really talking about, in one case, is sheer economics from the farmer's standpoint and, in the other case, a philosophical viewpoint. I want to emphasize this: it is sheer philosophy. They do not relate at all!

Charles Mercieca: Dr. Ehricke said that space is the business of experts but also the affairs of all people. I personally agree with that 100 percent. If it is the affair of all people, how can we reach all people? It seems to me that we can reach them most effectively through some type of educational approach. If this is true, then we have to think seriously of how we can reevaluate our educational systems in terms of priorities, of emphasis and school curriculums. One of the things that we also have to keep in mind is, what are the slogans that we have formulated so far in education, to stimulate our children to study and learn? They are deceiving. I have heard in this country, for example, both on radio and television, this slogan, "To Get A Good Job Get A Good Education." This, of course, is not true. I have met with people who were elementary and high-school dropouts and who are making $40 000 to $45 000 more a year than some of the best professors in the country. Paul Harvey said that plumber in California "makes more salary per year than 27 governors of the U.S." Now if this is true, I said to myself, the average governor is expected to at least have some sort of college schooling. Maybe he has a Bachelor, or Master. We are now moving from an education for nationalism to an education for internationality. This will be eventually the emphasis of the 21st century, where we emphasize education for internationality. But if we are the pioneers of the twenty-first century, then we have to find ways to meet these educational needs and change that slogan, "To Get A Good Job, Get A Good Education," which is based purely on the egotistical assumption that if I want to make more money I must get a good education. That is what education means for me, just making money for myself. Therefore, we have to formulate some other slogan, where emphasis is placed on not just to get a good education, but to do, say, a good job and life. One needs to get out himself and do something beneficial for the community, the state, the country — but we have to formulate this slogan properly. Now I would like someone here to tell us what we could do to try to take seriously this kind of approach of rebuilding a new educational system, what can we do as the first step? The second question is, what kind of slogans could we put forth in order to make this public affair a matter of fact?

John Hanessian: I do not know; you pose a very difficult problem. It is somehow related to the discussion going on in this country about foreign aid. I will go back to my lawyer training now. We have a very unfortunate thing in this world and that is that the "raison d'être" of most of the countries today seems to be state nationalism. In this country we are constantly thinking about what is best for America; the Frenchmen are certainly always thinking about what is best for France. But the same thing is true elsewhere. You go to Zambia, you go to Brazil — Brazil is really turning inward, because they have their own problems, very big problems. Wherever you go, it is a nation state, it is state sovereignty. "We have got to take care of ourselves." Yet, as I have said before, simultaneously the fact of our interdependency is growing constantly. If we do not have a Supersonic Transport (SST) today, we are going to have a Hypersonic Transport in a few years. You are going to get from here to New Zealand and back for lunch, so why are we increasing interdependence? The state is continuing on stronger and stronger than ever. I do not know the answer to this. Until we somehow find the way to knock down the barriers between states and thereby nationalism among people and replace it with a bit of universalism, we are not going to get anywhere. I am not optimistic about this, not at all. As I have said before, we now have 131 countries as members of the United Nations. We are going to have 150 and 160 before long; there is going to be a further fracturing of nation states. It is going to be one long cold day before we turn that into universalism. Perhaps, if we send Mr. Hubbard around, Mr. Diehl and a few people, maybe it would help. But I am not very optimistic.

Nicholas C. Costes: I have a question addressed to both Mr. Hubbard and Dr. Ehricke. When Mr. Hubbard was finishing up his commentary, he said — as I understood it — that unless man tries to go outside the realm of the terrestrial environment we are accelerating our doom. On the other hand, Dr. Ehricke has suggested that, if given sufficient time and sufficient funding, there is a possibility that we may be able to inhabit other planets, find other ways of life, and try to find a solution to what Mr. Hubbard alluded to. Now suppose the two are not synchronized? In other words, it takes much more time to try to acclimate ourselves to another planet or to try to find some other form of way of living in the space environment, and so forth. First of all, should there be a control in trying to improve ourselves on the planet earth? In other words, should we control our productivity or our improvement? In the second situation, suppose that, indeed, outer space is a dead space. The first remark that we had on Apollo VIII going around the moon was that this was a dead planet. What then? How do you convince the public that there is a certainty that, if they dumped money into outer space, we have a solution? Do you do that in this kind of a prospect, or because we have no other alternative but to turn to space, no matter what may happen?

Krafft Ehricke: The remarks of the lunar circumnavigating Apollo crew were very unfortunate, because they met a public that was not prepared to understand what actually the significance of the moon is. When I was a boy, I read very often that "If space were only filled with air, then we could fly with our aircraft somewhere else — but the terrible thing is that space is a vacuum." We know today that it is the most fortunate thing that could have possibly happened, because exploration of space or reaching other bodies would have been vastly more difficult if there had been air. Now that we get to our celestial bodies, we hear the same talk all over again, "Well, it is too bad that these other worlds are deserts, forbidding things — dead worlds!" Everything bad is being said; the fact is being lamented that they are not other earths. In reality, if they were other earths, then presumably there were other mankinds and we would really be fenced in. You see, the point is, there are not other earths; these worlds complement earth! They are not "dead" worlds; they just do not have the types of cycles that characterize our biosphere. Therefore, we can do things on them and provide materials and supplies through them for which the earth is too good to be used. There are certain things that you do not do in your good living room because it is a place of comfort and recreation and, at the same time, imposes certain constraints on you. That is why your wife is probably going to make you walk the dog or make you get the wood for the fireplace somewhere else, rather than from the furniture of the good living room. So what these worlds, these "dead" worlds, are providing us are those things for which earth is not unique — metals, metallic minerals that are very important because we live in an era of high-quality steel, not just an iron age, and we are running out of some of the materials that are needed to sustain our civilization. There are possibilities of applying nuclear energy to generate power and beam it onto earth. There are ultimately even possibilities of generating new, small biospheres on those other celestial bodies, starting off with a nuclear detonation, which is a very interesting parallel or analogy of the way our whole universe started — with one big bang. If you have one underground detonation on the moon of 1 kt TNT, you get tens of thousands pounds of oxygen right out of the rock. Then, if you fill that cavity up with hydrogen and detonate another 1 or 2 kt bomb — ridiculously small quantities of energy as compared to the quantities we hold at bay to throw at ourselves and each other — then you get thousands and thousands of pounds of water right then and there, because you get more oxygen out of the rock which reacts with the hydrogen in the cavity, and it comes out in the form of water. So you can create many things on these other celestial bodies.

The point that I was trying to make was this: The earth is a central planet for mankind for a long time to come, and there is no question about that. The central characteristic of the planet earth is the biosphere. The biosphere is too good to be exploited and ruined for sustaining man with things that we can get somewhere else, and can get economically. Economically, in the sense that it is more economical to pay a slightly higher initial price for transportation, even though it is not nearly as high as people in the average think it will be, rather than incur the long-range debt of ruining our biosphere. The latter is the much more costly situation; it is a unique thing. We would have to go to another stellar system before we might find anything like this again. So we are interested in those so-called "dead" worlds, precisely because we want to assure the survival of the living world.

F. I. Ordway: With what probability, at this stage of the game, will we find resources there? Do we know?

Krafft Ehricke: Oh, yes, we do know! We have lunar samples in hand. We know they are bursting with oxygen. There are metals and rare earths; for example, they have a higher concentration of titanium, at Tranquility Base, than anything found on earth. There are other ways in which we can determine some of these things.

Earl Hubbard: I think that the problem that the aerospace industry is facing is that they think they are selling a product, but they are producing a future. This, I suppose, could be called a philosophical point. I think the problem or the responsibility that aerospace industries have is to forget the idea of selling and to start thinking in terms of telling the American public the truth. You have computers; there is no credibility gap about your capacity to come up with the facts. Run through those computers models of what will happen if man continues to live on this earth, and run through them what will happen if you take on new worlds. Then run ads, all of you, as one campaign, on the needs of new worlds, and use split-page pictures — above: the virgin territories of the moon, below: the turbulence of an overpopulated world that is becoming increasingly irrelevant and meaningless, and across the center have the phrase "The need for new worlds." It was mentioned earlier that there was a difference between the philosophy and what is called pragmatics. This is true. We are moving into a new economy, we backed into the industrial revolution thinking it was a craft age. We are moving now into an evolutionary industrial age, and we do not know that either, therefore, we have to take on new worlds first, since philosophy only means a sense of direction. If we say we are going to new worlds, we have a set of values. It is the same thing as if you go out into the desert where you set a very high value on water but you place a low value on a rowboat. Now, if we take on new worlds, then we can establish a set of priorities, a set of values. If you present the facts to the public that there is a declining need for man on this earth, they will accept this and, I believe, react in a very positive fashion.

Jesco von Puttkamer: I would like to thank our distinguished panel and also the audience for raising such interesting questions. This brings our Forum and Congress to a close. Thank you all very much.

Transcribed from tape

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House of Representatives

MONTGOMERY, ALABAMA

OFFICE OF THE CLERK

# Resolution

H.J.R. 62

By: Mr. Hale

RESOLUTION COMMENDING THE HUNTSVILLE ASSOCIATION OF TECHNICAL SOCIETIES FOR SPONSORING "A SPACE CONGRESS FOR THE NON-AEROSPACE PUBLIC."

WHEREAS, The Huntsville Association of Technical Societies, jointly with the major Technical Societies of Huntsville, Alabama, the City of Huntsville and the State of Alabama, propose to sponsor within the City of Huntsville, Alabama, November 15-19, 1971, "A SPACE CONGRESS FOR THE NON-AEROSPACE PUBLIC"; and

WHEREAS, The theme of said congress will be "SPACE FOR MANKIND'S BENEFIT", and will be an attempt at developing an interpretation of the practical aspects of the space program in popular language and conveying it to the public; and

WHEREAS, The Honorable Spiro Agnew, Vice President of the United States of America, has been invited to attend and address the congress; and

WHEREAS, The conference will investigate the broad range of concrete benefits to mankind which has resulted from the space effort, giving the public an opportunity to share the evidence of the practical benefits from space; and

WHEREAS, The program will provide many outstanding nationally known speakers on the various topics of discussions and will include lectures, luncheons, banquets, and the delivery of papers on the subject in non-specialist popular language; and

WHEREAS, It is the judgment and opinion of the Alabama Legislature that the program planned by the Huntsville Association of Technical Societies will provide many benefits to the citizens of Huntsville and to the State of Alabama.

NOW, THEREFORE, BE IT RESOLVED BY THE HOUSE OF REPRESENTATIVES, THE SENATE CONCURRING, That we do hereby commend the Huntsville Association of Technical Societies for their ingenuity and wisdom of forethought in sponsoring such an event and that we do hereby endorse the proposed space congress; and

BE IT FURTHER RESOLVED, That a copy of this resolution be sent to the Huntsville Association of Technical Societies and to each participating technical society of Huntsville.

I hereby certify that the above resolution was adopted by the Legislature of Alabama June 30, 1971.

John W. Pemberton

John W. Pemberton
Clerk

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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